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DEVELOPMENT DIGEST

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CONTENTS

Volume XIV - Number 3

July 1976

FISHERIES

- | | |
|--|----|
| THREATS TO WORLD FISHERIES Erik P. Eckholm | 3 |
| FISHERY AND RESOURCE MANAGE- MENT IN SOUTHEAST ASIA John C. Marr | 9 |
| EFFECTIVE FISHERIES MANAGEMENT WITH REGIONAL DIVERSITIES Francis T. Christy, Jr. | 26 |
| HIDDEN RICHES OF PONDS <u>Técnica Pesquera</u> | 38 |
| THE OCEAN FOOD AND ENERGY FARM PROJECT Howard A. Wilcox | 42 |

ENERGY AND AGRICULTURE

- | | |
|---|----|
| ENERGY AND AGRICULTURE; AN EDITORIAL INTRODUCTION Gordon Donald | 51 |
| INTERACTION OF ENERGY AND FOOD PRICES IN DEVELOPING COUNTRIES C. Peter Timmer | 54 |
| ENERGY AND FOOD PRODUCTION Gerald Leach | 59 |
| FUEL FOR AGRICULTURE IN THE THIRD WORLD Arjun Makhijani | 69 |

FOREIGN INVESTMENT

- | | |
|--|----|
| HOST COUNTRIES AND MULTI- NATIONAL CORPORATIONS Dale R. Weigel | 89 |
|--|----|

ECONOMIC NATIONALISM AND
THE COPPER INDUSTRY
Theodore H. Moran

97

INTERNATIONAL
SUB-CONTRACTING
Michael Sharpston

107

(Unless otherwise indicated
currency is expressed in U. S. dollars.)

FISHERIES



BONITO CAUGHT IN A PURSE SEINE, TAIWAN
(PHOTO: OFFICE OF INFORMATION
COMMISSION ON RURAL RECONSTRUCTION, TAIWAN)

Threats to World Fisheries

Erik P. Eckholm

[The supply of fish from the ocean is proving highly vulnerable to the rapidly growing capacity for fishing with modern methods; important species are being depleted, yet fishing fleets are expanding. The Peruvian anchovy are a dramatic example of the problem and an illustration of the need for controlled management.]

Until quite recently, the oceans have seemed nearly boundless and endlessly bountiful. Fish have almost always been there more or less for the taking; the size of the catch was dependent only on the fisherman's efforts and skills. Early fishermen were restricted to inland ponds, rivers, and ocean coastlines. First on logs, later on rafts, and finally on boats, their ability to capture fish away from the shorelines grew, but the problem of spoilage still held most fishing vessels to within several hours of population centers. The nineteenth century introduction of ice storage on fishing boats greatly expanded their range, permitting cruises of two to three weeks. By the mid-twentieth century, massive fleets and floating factories able to process and freeze fish right on board could make journeys of many months and, with the aid of helicopters and sonar, could locate and chase down schools of fish almost anywhere.

In the face of improved fishing capacities and a soaring world demand for protein, the oceans have been generous. Between 1950 and 1970 the world fish catch more than tripled; rising from twenty-one million to seventy million metric tons, it reached a new record almost every year. The global catch grew at over 5 percent annually, or more than twice

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as fast as world population, thus significantly augmenting the per capita supply of marine protein. The 1970 world catch averaged out, in live weight, to nearly forty pounds per person.

Fish are an important protein source in many of the world's more populous countries, including Japan, where the average person consumes seventy-one pounds per year; the Philippines, where consumption averages forty-four pounds; and the Soviet Union, where twenty-three pounds is the average. These figures do not include the third of the world catch that is ground into feed and eaten almost entirely by poultry and hogs in Japan, Europe, and the United States. Though the richer countries catch or buy a disproportionate share of the total, fish are virtually the only source of high-quality animal protein for hundreds of millions of the world's poorest people in parts of China, Southeast Asia and elsewhere.

In the mid-seventies, as the era of rapid growth in world fisheries draws to a close, difficult questions are coming to the fore: does human society possess the organizational capacity to preserve this valuable, renewable resource at a high level of productivity? What criteria will be used to divide up the finite ocean harvest when the rich and the poor, the overfed and the malnourished, the powerful and the weak all clamor for more animal protein? The continuing United Nations Law of the Sea Conference marks a transitional period to a new order in the oceans. It remains uncertain whether this will be an order of international cooperation or conflict, of enlightened fisheries exploitation or myopic resource destruction.

How much longer can we expect the world catch to grow? Food and Agriculture Organization scientists, in collaboration with fishery scientists and institutions throughout the world, recently estimated a maximum sustainable world catch of roughly one hundred million metric tons annually. This total includes all species currently sold in the world's fish markets ranging in size from whales to anchovies, and also species not yet exploited commercially but similar in size and appearance to those that are. It assumes that currently underfished regions like the Indian Ocean, the South China Sea, and others will be exploited; that few major stocks will be seriously depleted by overfishing; and that pollution will not destroy marine life over significant areas. Not taken into account is the large-scale utilization of new species low on the food chain, such as the Antarctic krill, a prolific plankton with harvest possibilities of up to fifty million tons should the problems of cost and palatability that now limit its exploitation be overcome. Nor does the estimate include large potential production increases through aquaculture, or inland fish farming.

The possibility of raising the annual global catch from its current

seventy million tons to one hundred million tons seems an encouraging conclusion until one runs through the mathematics of growth. If the rate of increase in the world catch of the 1950-70 period could be maintained, the estimated sustainable limit of one hundred million tons would be reached in just eight years. Even if the FAO estimate turns out to be overly pessimistic, and the catch could be doubled to 140 million tons, as some feel is possible, this higher limit would be reached in fourteen years at the 1950-70 growth rate. Every major fishing nation plans to increase its catch, and fleets expand every year; but it remains an open question whether or not the international power to limit fishing efforts can be developed before the potential additions to the catch are used up. An overextended world fleet could rush past the safe limit quickly, severely damaging many species and causing a partial collapse of the oceanic harvest. More likely, the growth in catch may now slow down markedly despite intensified fishing efforts, as the catch of the more easily captured stocks peaks and in some instances declines. In either case, the world will probably not experience a sustained, dramatic increase in the supply of marine protein again.

By the early seventies, serious stresses in the oceanic system had already emerged, raising doubts in some quarters as to whether the catch will ever reach even one hundred million tons. Two decades of continual growth came to an abrupt halt in 1971, when the catch fell to just below the previous year's total of seventy million tons. Then, in both 1972 and 1973, as the important Peruvian anchovy fishery temporarily collapsed, the total world catch dropped still further to under sixty-six million tons. The preliminary estimate for 1974 shows a catch that is back up to the 1970 level, between sixty-nine million and seventy million tons. This sharp dip in the supply of marine protein caught most analysts off guard. The spectacular growth had obscured the less prudent aspects of the process by which that growth was achieved. Hidden beneath the overall growth figures was a continual movement to new species and regions as traditionally preferred species were fished to minimum replacement levels or beyond. A few species have now been virtually wiped out altogether, some have been depleted to a fraction of their potential yield, and many are producing at below their maximum level due to overly intense fishing pressures.

The process by which some fisheries have grown, suffered over-exploitation, and then declined is shown in the experience of the Northwestern Atlantic offshore region extending from Rhode Island northward to the southern coast of Greenland. Fished commercially for 350 years, and accounting for 5 percent of the total world catch, this region is in some ways a microcosm of world fisheries and a harbinger of things to come elsewhere. The northwest Atlantic is biologically rich and, as the Soviet and European fleets joined those

of Canada and the United States, the area's fish harvest rose steadily from 1.8 million tons in 1954 to a peak of 3.9 million tons in 1968. But though the level of fishing effort has grown with each succeeding year, the total catch has not surpassed 3.5 million tons in any of the five following years for which data are available.

The falling catch of several of the region's most sought-after species is largely due to overfishing and explains the drop in total output. The harvest of cod, the most important single species, reached a high of 1.9 million tons in 1968; by 1973, it had fallen by more than 50 percent. The catch of herring also peaked in 1968, at 0.9 million tons, and was down to 0.5 million tons in 1973. The had-dock catch turned the corner earlier, in 1965, when the catch reached 249,000 tons; it had fallen to little more than a tenth of that level by 1973.

The nations fishing in the area have long maintained an International Commission for the Northwest Atlantic Fisheries to collectively oversee the fishery. Though the commission has not been able to reduce fishing efforts to a safe and economically sensible level, its recent strenuous efforts to reduce the pressure on the more gravely threatened species in various sub-regions have, in some cases, helped prevent their total depletion.

Peruvian anchovy. In the southeast Pacific Ocean, off the Peruvian coast, the world's richest fishing ground has just experienced a convulsion that parallels strikingly such terrestrial ecological breakdowns as the recent Sahelian debacle and the American Dust Bowl of the thirties. When a sudden but predictable change in natural conditions occurred that temporarily reduced the system's capacity to support life, the confluence of pressures imperiled both humans and the natural system. This story began in the mid-fifties, when the fishing industry of Peru began the most spectacular expansion in the history of marine fisheries. Ocean conditions off the coast of Peru and northern Chile facilitate an extraordinary concentration of life there. A westward swing of the Humboldt Current, which flows toward Peru out of the South Pacific, causes a cool, nutrient-rich upwelling from the depths, and, as it reaches sunlight, there is a rich bloom of plants and animals.

In the nineteenth and early twentieth centuries, humans capitalized upon this ecosystem by collecting for sale as fertilizer the manure (guano) of sea birds that fed upon the billions of anchovies swarming off the coast. Governmental regulations in reaction to the foreseeable exhaustion of the guano helped dampen this trade, but a new industry, based one step lower on the food chain, emerged. At a time when technological progress permitted more efficient culling of the anchovies, rising incomes and a revolution in the poultry industries of Europe, Japan, and North America were creating a lucrative new mar-

ket for the fishmeal into which the anchovies are ground. Unfortunately, the anchovies, a vast source of high-quality protein, have been mainly used not to eliminate malnutrition in Latin America, but to help satisfy the growing taste for meat in the industrial countries. In part because of the prolific anchovy, fishmeal has become a frequent protein additive to feeds for broiler chickens that are often now produced in huge, scientifically fed concentrations. As the catch soared in the mid-sixties, Peru became the world's leading fishing nation; its anchovy catch accounted for a fifth of the entire world fish catch in many years. Often, nearly two-thirds of the world's fishmeal exports came from this one country.

High profits generated massive over-investments in fishing vessels and fishmeal-processing plants. Though an excellent system of biological monitoring and fishing regulation was developed, the combination of too many investors with too many boats and the government's hunger for foreign exchange generated strong pressures to continually increase the anchovy harvest. In 1970, an international team of biologists estimated the maximum sustainable yield of the Peruvian anchovy fishery at about 9.5 million metric tons. Political realities had stronger exponents than biological needs, however; the catches in 1967, 1968, 1970, and 1971 all exceeded this estimate, and reached a height of over twelve million tons in 1970.

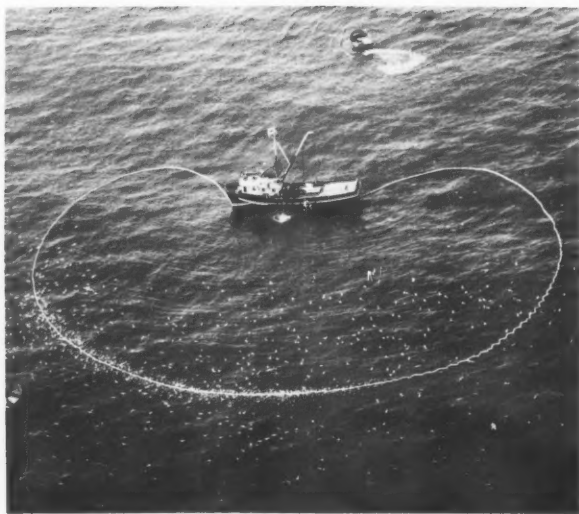
The anchovy stock had long been known for its instability; an unpredictable warm current, locally known as el niño, periodically drives the anchovies deep in search of colder water, and possibly reduces their numbers. In mid-1972, after heavy fishing in the spring, it became apparent that the anchovies had vanished from their usual coastal haunts in the wake of el niño. Alarmed by their absence, the Peruvian government halted fishing for the rest of the year. In early 1973, the characteristics of the current remained unusual, and experimental catches indicated the absence of a new brood of anchovies. Fearful that the fishery would be permanently destroyed, the Peruvians closed it for most of that year and part of the spring of 1974. For almost two years, the world's greatest fishery lay virtually idle—two very long years for the fishermen, who were out of work; for the industry owners, some of whom lost fortunes; for the Peruvian government, which lost its chief export; and for consumers everywhere, who found the world protein market disrupted by the sudden shortage of fishmeal.

There has been a tendency in many quarters to ascribe this collapse entirely to nature and el niño, but a careful examination of events makes that explanation unsatisfactory. In hindsight, observes John Gulland, a leading FAO fisheries expert, it appears likely that the overfishing of 1970 and 1971 depleted the stock to such a vulnerable condition that, "while recruitment [successful replenishment

by a new spawning] could be maintained under average or better environmental conditions, the unfavorable conditions of el niño would cause a recruitment failure that would not have occurred if the adult stock had been larger." After the particularly heavy catch of 1970, an exceptionally small brood was produced in 1971—well before el niño struck. The fishing effort of early 1972 apparently finished off the survivors of both the 1970 and low 1971 spawnings, leaving few adults to replenish the species. By comparison, el niño caused only a brief and modest drop in the anchovy catch in 1965, after annual catches under the recommended level, and did not disrupt the following year's brood.

In 1973, the Peruvian government nationalized the fishmeal industry as part of an effort to reduce its overcapacity. The number of anchovy fishing boats was cut in half. Under the guidance of marine biologists, the government also tightened management of fishing levels. In 1974, as the fishery began to regenerate, a catch of just 3.6 million tons might be permitted. With the new degree of management, biologists hope the fishery will be back to normal by 1977; presumably, fishing will henceforth be held to a sustainable level.

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stitute.]



Fishing boat with net
off the coast of Chile
(Photo: Interamerican
Development Bank)

Fishery and Resource Management in Southeast Asia

John C. Marr

[This article describes the composition of fish stocks of the South China Sea and the fishing activities of countries on its borders. It then discusses the problems of fishery management and the consequences of various policies, concluding that a strong regional organization with authority to make regulations is needed for viable solutions. This presentation of fishery problems in a particular region serves as an introduction to the global discussion of these problems in the next article.]

For the purposes of this review, Southeast Asia includes the South China Sea and the countries bordering it: China and Taiwan to the north; the Philippines in the east; Indonesia in the south; Malaysia - south and west; Thailand, Cambodia and Vietnam (north and south) to the west; along with Singapore, Hong Kong and Brunei. The South China Sea contains a deep basin, the China Sea Basin, as well as extensive continental shelf areas. The main shelf areas are the Mainland Shelf off China, including Taiwan and Hainan islands and Tonkin gulf; and the Sunda Shelf which covers ocean area to the south and west of a line running from South Vietnam across to Brunei, including the Gulf of Thailand. (The definition of the shelf areas as those with water less than 500 m deep is used here because modern trawlers can operate to that depth.) Adjacent to the South China Sea are several smaller seas, which are claimed as internal waters or territorial seas by Indonesia and the Philippines.

Productivity of fisheries is high in the continental shelf areas, although low in the surface waters of the

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deep areas. Enrichment is brought about by vertical mixing in the shelf areas, river discharge, and upwelling. In the South China Sea, vertical mixing over the continental shelf is undoubtedly the main mechanism for nutrient replenishment in the surface layers, followed by river discharge, and upwelling, in that order. Production of fish, crustacea and mollusca is high in the shelf areas. In general, this production is spread over a very large number of relatively short-lived species. Unlike fisheries in the higher latitudes, which are based upon one, or at most, a few long-lived species which tend to accumulate on the fishing grounds, fisheries in the tropics, and especially in the South China Sea, are based upon large numbers of short-lived species. It is, for example, not uncommon to take as many as 200 species in a single trawl haul, a factor which has major implications for fishery development and management.

Important Fisheries

Four countries—China, Indonesia, the Philippines, and Thailand—account for over half of the total production in the South China Sea, but fisheries are of importance to almost all of the South China Sea countries. Only two countries, Brunei and Singapore, have an annual production less than 100,000 metric tons. The fisheries pursued are many and varied, and the fishing gear employed is also varied, including several kinds of trawls, purse seines and other encircling nets, lift nets, gill nets, bagnets, castnets, beach seines, surface longlines, bottom longlines, hook and line, trolling lines, several kinds of stake traps, fish pots, etc.

The major pelagic fisheries, in descending order of importance, are those of the Philippines, Indonesia, Thailand, and Taiwan. (Pelagic fisheries are those based on fishes living near the surface or in midwater, generally not associated with the bottom. Demersal fisheries are those based on species living on or near the bottom.) The important species in the Philippines' pelagic fishery are round-scads, sardines, bigeyed scads, and chub mackerel, all of which are taken in the purse seine-light and bagnet-light fisheries. In Indonesia the major species are Spanish mackerel, fusiliers, and anchovies, taken largely by liftnets and gillnets. The major pelagic species in Thailand are chub mackerel, squid and cuttlefish. Chub mackerel are taken by gillnets, purse seines, and pair and otter trawls; squid and cuttlefish are taken by trawls. In Taiwan the important species are mackerel, bonito, horse mackerel, gray mullet, moonfish, bunas, dolphin, and shark. The gear employed includes purse seines, longlines, and handlines. (Tuna fishing, which presents special global problems, will not be discussed here.) The major demersal fisheries are those of Thailand, China, the Philippines, and Taiwan. These trawl fisheries are based upon large numbers of species; some species groups are widespread, while others are less so. In the southernmost areas there is a tendency for any

one species or species group to make up a smaller proportion of the total catch.

National distribution of fisheries. Fishermen from China, Indonesia, the Philippines, Malaysia, Cambodia, and the two Vietnams have remained largely in their national waters. The Southeast Asian countries fishing in more distant waters are Taiwan, Thailand, Hong Kong, and Singapore. The Taiwanese demersal fleet includes baby trawlers (smaller than 50 tons) of which perhaps half the fleet (about 1000 boats) fish in the area off Luzon and Kalimantan where they took about 52,000 metric tons in 1971. The distant-water fishing by Thailand has come about from the pressure induced by overcapitalization of the Gulf of Thailand fishery and the resultant decline in profitability. Starting in 1967 many trawlers moved out of the gulf and operated in the area off South Vietnam. The 1969 catch of these boats was slightly more than 300,000 metric tons, nearly half of the gulf of Thailand catch. Hong Kong trawlers fish from east of Hong Kong to the southwest of Hainan.

The total fishery production of Singapore is about 15,000 metric tons, although total consumption is several times this amount. Currently production fishing is declining in Singapore, owing to more attractive investment opportunities ashore. In 1966, when there was considerable unemployment in Singapore, the government adopted a program to develop a large fish harbor complex at Jurong, which includes unloading facilities, cold stores, auction and market, ice plants, bunkering, processing plant sites, etc. This is used to receive landings from local boats and also import landings for consumption or re-export from foreign boats - chiefly from Thailand, West Malaysia and Indonesia. Vessels from Japan and the USSR have also used Jurong.

The main fishing country from outside the region today is Japan. At present, the Japanese tuna longline fishery produces about 3200 metric tons annually, largely from deep-water areas beyond the shelf. Fishing efforts in northern waters decreased with the escalation of the war in Vietnam and ceased altogether after 1963, but the Japanese government has recently granted permission for pair trawlers to operate in the South China Sea north of 10° north latitude. In Indonesia, a Japan-Indonesia fishery agreement, originally concluded in 1968 and renewed from time to time, permits Japanese vessels to fish within Indonesian waters on a fee-paying basis.

Potential production. Only a few decades ago tropical areas in general were considered to have a very low productivity. In fact, however, the tropics can be very productive, and the South China Sea area is one of the most productive in the world. A number of estimates of potential yields of the South China Sea have been made,

Table 1: Fish Catches of South China Sea Countries, Primarily 1971
(1,000 metric tons)

| | South China Sea Only | | | Total from all sources ^a |
|----------------|----------------------|---------|---------|--|
| | Demersal | Pelagic | Total | |
| Brunei | 0.8 | 0.6 | 1.4 | 2 |
| Cambodia | 27.5 | 7.0 | 34.5 | 77 |
| China | 410.3 | 144.4 | 554.7 | 6,880 |
| Hong Kong | 83.7 | 28.3 | 112.0 | 114 |
| Indonesia | 50.0 | 283.2 | 333.2 | 1,245 |
| Laos | - | - | - | 20 |
| Malaysia | 223.7 | 138.8 | 362.5 | 368 |
| Philippines | 208.5 | 598.3 | 806.8 | 1,050 |
| Singapore | 11.0 | 3.3 | 14.3 | 15 |
| Taiwan | 233.4 | 217.4 | 450.8 | 650 |
| Thailand | 984.5 | 261.7 | 1,246.2 | 1,587 |
| Vietnam, North | 115.0 | 100.0 | 215.0 | 300 |
| Vietnam, South | 309.6 | 206.4 | 516.0 | 587 |
| TOTALS | 2,658.0 | 1,989.4 | 4,647.4 | 12,894 |
| Japan | | 3.2 | 3.2 | 9,949 |

Source: FAO

a. Includes in addition fresh water fish from ponds and rivers, and catches from other ocean areas: primarily the former for China and other mainland countries, the latter for Japan, and both for Indonesia.

the most recent of which project an increase over the 4.6 million tons in 1971 by about 3 million metric tons. An earlier estimate (FAO, 1969) of total potential production in the South China Sea and adjacent seas ranged from 4.9 to 7.2 million metric tons, and other estimates have run over 10 million tons. Historically speaking, estimates of fishery potential tend to be conservative; it may be expected that the potential increase in South China Sea fishery production will be at least 3 million metric tons, most of it in the Sunda Shelf area.

The Problems of Management

In Southeast Asia, the problems of fishery development and management follow a pattern that has become all too familiar throughout the world in the decades after World War II. They include overcapitalization, biological overfishing, fishery management (including allocation or distribution), resource management, and political problems. Overcapitalization, and thus economic waste, are inevitable in a fishery in which there is unlimited entry. This common property charac-

teristic is particularly difficult, if not impossible, to change in the absence of jurisdiction. In brief, the waste is caused by open access and redundant vessels: low returns to fishermen are caused by the time lags between events in the fishery and the time that these are perceived by investors, and between the time a decision is taken to build a boat and the time when the boat enters the fishery. When a fishery first starts, it is usually very profitable. This causes the entry of additional boats, either by new construction or by movement from another fishery. As the number of boats entering the fishery increase, the total catch is divided among more and more boats and individual profits decrease. Eventually the point is reached at which income just covers operating costs; beyond this number of boats there will be a net loss, and presumably the less efficient boats will be forced out of the fishery. This sequence of events will be inevitable unless there is control of the fishery in such a way that the number of vessels entering the fishery is restricted to that level appropriate to the yield of the fishery.

Biological overfishing is not inevitable. If the level of fishing effort at which biological overfishing occurs is substantially greater than the level of effort at which the fishery becomes unprofitable, then biological overfishing most likely will not occur. On the other hand, if the two levels are very close, then biological overfishing most likely will occur. If world demand and the price of fish rise rapidly relative to production costs, then the fishing effort level at which the fishery remains profitable will become increasingly larger, greatly adding to the likelihood of biological overfishing.

Biological overfishing can be of two kinds. First, it frequently, but not always, happens that the relationship (generally referred to as the yield per recruit relationship) between gain in weight of a group of fish—say, members of a single year-class, through growth of its members and loss in weight through death of some of its members—is such that there is a maximum weight of the group at some particular age. If the fishery is so intense that the maximum weight is never reached, then biological overfishing has occurred. Second, there may be a stock and recruitment relationship operating in such a manner that a large spawning stock size produces a large recruitment and a small stock size produces a small recruitment. It is by no means clear that this is generally the case or for how many species. Still, if it is the case, then a high level of fishing effort would reduce the spawning stock size which in turn would reduce the amount of recruitment. It is almost impossible to obtain information on the stock and recruitment relationship; indeed, this is one of the most perplexing problems of fishery biology. Given adequate information, it is possible to work out the yield per recruit relationship; but in situations where one does not have simple and reliable catch and effort data, it is not likely that this kind of information will be available. Furthermore, fisheries may develop so rapidly that, for

management purposes, there simply isn't enough time for elaborate analyses or for those requiring relatively long time-series of data.

Fortunately, if catch and effort data are available, it is possible to determine the maximum sustained yield of which a resource is capable. Management of a resource by setting the maximum sustained yield as a total catch quota will conserve the resource; but allowing unlimited entry to the fishery will inevitably lead to economic loss. Losses from overcapitalization can be avoided only by limiting entry according to the potential yield of the resource. Thus, it is the fishing effort rather than the total catch which should be regulated.

Barriers to this kind of management in the Southeast Asian countries include the lack of adequate catch and effort data, of resource information, and of technical staff. Still, most if not all countries in the region have a statistical base and a staff base upon which to build. Indeed, in some countries the technical staff, if not the statistical system, is of a very high order indeed. Perhaps a more important barrier is the political difficulty in implementing needed fishery management decisions. An example, by no means unique, is the trawl fishery in the Gulf of Thailand. The Thai government, through its own survey cruises had good information, on a current basis, about what was happening in this fishery and had been forewarned as to the consequences of allowing the fishery to develop in an uncontrolled manner. Nevertheless, it was apparently easier politically to suffer the consequences of following a policy of unlimited entry with no catch quota than it was to restrict entry into the fishery at an appropriate level.

The most difficult problem connected with limiting entry into a fishery is that of allocation: who is to receive the benefits from the fishery? Some of the criteria frequently advanced include proximity, manageability, historic rights, need, capacity to exploit, and common heritage. While there are arguments in support of each of these, there are frequently equally valid arguments against them. In any case, even if these or other criteria could be accepted in principle, they would be difficult to apply in practice. For example, what constitutes proximity?

Let us assume that fishery jurisdictions are extended to 200 miles. The southern Sunda Shelf fishery resources would then lie primarily in the extended zones of Indonesia and Malaysia. It would be a fairly straightforward task to determine the maximum sustained yield of, say, the demersal resources of the area (ignoring for the moment the movement of resources between two or more zones). It would also be a fairly straightforward task to determine the amount of fishing effort necessary to take the maximum sustained yield or, better, the

amount of fishing effort necessary to maximize the economic yield. Then, within the Indonesian zone, it would be fairly simple for Indonesia to allocate the fishing rights to its own nationals because the government already has the authority to make such allocations, and there is presently very little fishing by Indonesia within the zone. But Taiwan, Thailand, and Singapore have been fishing in the area, some for many years and with a substantial annual catch. Such countries could press claims for the right to continue fishing in the area on the basis of their records—historic rights—and because of Indonesia's inability to immediately harvest the resources at the maximum level. Other countries, such as Korea and Japan, might then press their claims on the basis of the latter reason, and also upon their need for additional sources of food. While Indonesia, in this illustration, might find it easy to resist some of these newer claims, the claims of historic right might well prove difficult to resist. If such claims were recognized, they could be limited to some specified period of years, after which the right would no longer exist. A country in the position of recognizing such a right—Indonesia—would also wish to capture some benefit for itself, particularly if it were not itself able to exploit the resource immediately. Thus, the recognition of historic rights might be made dependent upon the payment of a fee or rent for the exercise of the historic right. Or the recognition of foreign rights might be conditional on the formation of a cooperative venture with nationals of the country of jurisdiction.

Finally, there are political problems in the region which impinge on fisheries: it is not reasonable at this time to expect China and Taiwan to sit down together at the conference table in order to negotiate the management of fishery resources. In other cases there are conflicting territorial claims, as well as problems of political compatibility which are not wholly predictable.

Some Aspects of Management in South China Sea Conditions

Mention has been made of the tremendous proliferation of fish species, some 2500, in Southeast Asia. This multiplicity of species has several implications with respect to Southeast Asian resource management and fishery management. First, there are almost no single-species fisheries in this area, whereas they are common in the high latitudes. Second, the ratio of fishery scientists to the number of species is so unfavorable that the kind of information commonly believed necessary for management simply will not become available in the future except for a handful of species; and third, because of this, some new approaches to management must be found.

Although it is true that some of the pelagic fisheries, such as the Rastrelliger or chub mackerel fishery in the Gulf of Thailand, may take only one or a few species, the demersal fisheries are universally multispecies fisheries, with individual trawl hauls containing as many as two hundred species not uncommon. Many species are taken, but usually not many individuals of a single species are taken in any one catch. For example, in Thailand shrimp generally occur as a by-catch in the trawl fishery for fish, and their relatively high value makes it profitable to sort them out of the mixed catch. Generally speaking, then, processing and marketing arrangements which require large volumes of single species will not develop in the South China sea demersal fisheries. About one-third of the demersal catch consists of "trash fish," that is, fish for which there is not a ready market for direct human consumption, either because the species are not in demand or because the fish taken are small juveniles of otherwise acceptable species. In Thailand, and to a lesser extent elsewhere, this trash component of the catch is not discarded dead at sea, but is used for duck food, catfish food, or for the production of fish meal, so that it is not wasted. If there were no market for it, the mesh size of the trawls might be increased, allowing the small fish (and, it should be noted, the shrimp as well) to escape relatively unharmed. From a resource management viewpoint this might be preferable, although these alternatives have not been compared critically to my knowledge.

Because of such ecological complexity and the disparity between the number of scientists and the number of fish species, as well as the urgency of management problems, the development of new management technologies and new ways of conceiving and handling fishery management problems is essential. Although it is obvious that the needed new technology cannot now be specified in detail, some of its characteristics can be. Foremost among these is the need—especially for the trawl fisheries—for methodology which will enable treatment as a single unit of the entire ecological assemblage upon which the fishery is based. Indeed, a major step in this direction has already been made by Gulland (1972), Isarankura (1971), and others. Another aspect is the possibility of influencing the species mix in the fishery in a desired way through appropriate regulation of fishing intensity. Tiews et al. (1967) have reported the change in relative abundance of the components of the trawl catch in the Gulf of Thailand over only a three-year period. Subsequently, cephalopods have increased greatly in the catch relative to fish. Eggleston has remarked on the change in relative abundance over time in the Hong Kong trawl fishery, with deep-bodied species becoming less abundant relative to long-bodied species. Thus, it may be possible to bias the species mix in favor of those species in greatest demand (that is, of highest value) by fixing fishing intensity at the appropriate level.

An additional point is the almost complete lack of information on the distribution or range of the self-perpetuating population units. For example, suppose that a species is known to occur from Taiwan to Indonesia: is it a migrating species—one in which individual fish move between the two areas? Then, obviously, what happens in the fishery in Taiwan will have an effect on the fishery in Indonesia, and vice versa, and any management scheme must take this into account. Or, is it a sedentary species—one living in separate areas with virtually no movement from one area to another? Then fisheries in Indonesia and Taiwan will have no effect on each other. It is known that many species in the area are wide-ranging. In fact, of the 324 commercially important species listed by the FAO, only three are restricted to one country and only nine restricted to two countries, so that 312, or 96 percent, are found in three or more countries. There is the possibility of more or less local, self-perpetuating population units within widely distributed species. But information on this possibility is simply not available within the medium-term future for more than a small number of species at best. Lacking evidence to the contrary, it must be assumed that a substantial proportion of the resources should be regarded as multinational rather than strictly national, and the management regime will need to be international.

The Alternatives

Alternatives for dealing with the management of fisheries in the South China Sea fall under three headings: (1) continuation of the status quo, (2) the extension of fishery jurisdiction, and (3) the provision of management mechanisms. The last might include bilateral arrangements, which in the South China Sea area would appear to be the joint venture or cooperative venture; multilateral arrangements; and possibly, although not very likely, regulation by existing multinational organizations.

Continuation of the status quo will mean an extension of overcapitalization of the fisheries, biological overfishing of the resources, and increasing confrontation between countries. Overcapitalization will continue to occur, not only within individual countries but also when two or more countries exploit a single fishery resource as though each were the only one involved. This may be expected to occur with respect to the demersal fisheries on the southern Sunda Shelf and the pelagic fisheries of the South China Sea. As demand for fishery products continues to grow, biological overfishing may be expected to follow overcapitalization. As these conditions become more marked, there will be increasing confrontation between countries; and the intrusion of the fishing boats of one country into the territorial waters or exclusive zone of another, already happening in the region, will occur with increasing frequency. Undoubtedly,

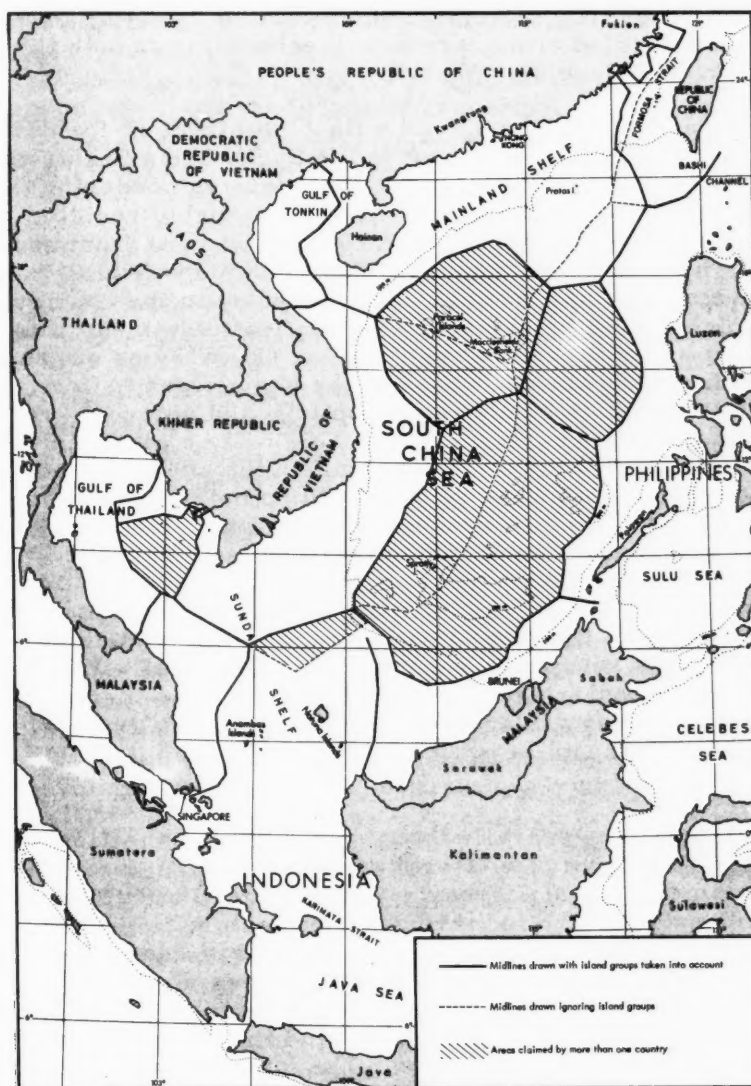
when these conditions become so serious that they can no longer be ignored, countries will attempt to reconcile the differences and to impose some sort of management regime. However, there is a wealth of experience elsewhere in the world which demonstrates conclusively that it is very difficult to reverse such situations and that, in any case, it is much easier, as well as much more efficient, to manage fisheries and resources prior to the onset of overcapitalization and overfishing.

Extension of Fishery Jurisdiction. The present zones of claimed fishery jurisdiction by Southeast Asian countries are mostly rather narrow—leaving aside the special situation of the archipelago states of Indonesia and the Philippines. It seems inevitable that these zones will be extended in the near future, that not only will the shelf areas in the north, west and south be brought under the jurisdiction of individual countries, but that the extension will probably be 200 miles (or to the midlines, when the distance between countries is less than 400 miles), so that all of the South China Sea will fall under various national jurisdictions.

The boundaries of extended jurisdiction zones—if these were extended to 200 miles, that is, to the midlines in the South China Sea—are shown in Figure 1. Ignoring the outlying island groups, the broken line indicates the midline. The solid lines indicate midlines drawn when these island groups are taken into account. Islands or island groups claimed by more than one country give rise to conflicts affecting the shaded areas on the map. Hence, the solid lines have no connotation as to how these conflicting claims will be resolved. The magnitude of the areas involved, and the fact that oil deposits are or may be involved, suggest that these conflicting claims will be difficult to resolve.

It is to be expected that the distant-water fishing countries in the South China Sea area will oppose the extension of fishery jurisdiction should such jurisdiction carry exclusive rights to fishery resources. Thus, the important question about the extensions of fishery jurisdiction in the South China Sea is, as elsewhere, what is the content of such jurisdiction? For varying reasons it might be expected that China, Indonesia, Cambodia, Malaysia, the Philippines, and North and South Vietnam would favor exclusive jurisdiction for the coastal states. It may also be expected that Hong Kong, Singapore, Taiwan, Thailand, and, of course, distant-water countries such as Japan would strongly oppose exclusive jurisdiction, although they might not oppose it if the extension is not exclusive but is constrained by certain international rules. That is, these countries might be expected to favor the "full-utilization" proposal, which provides that a country not fully utilizing its own fishery resources must permit fishing by the nationals of other countries.

Figure 1. Boundaries of jurisdictional zones extended to the midlines in the South China Sea



The extension of jurisdiction may facilitate rational controls in those cases where a fishery resource previously used by two or more countries becomes, by virtue of the extension, subject to the jurisdiction of only one country. But since the fish will move freely

between jurisdictional zones, in many cases the extension of jurisdiction alone will not solve the international problems of overcapitalization and biological overfishing. Clearly, while extension of fishery jurisdiction zones may not only be inevitable but useful, there also needs to be provision of management mechanisms at both the national and international levels.

Management Mechanisms. The first requirement for dealing with international fishery management in the South China Sea area is an internal management mechanism in each country bordering the sea. The exact nature of such mechanisms—presumably residing in a department of fisheries or its equivalent—will vary from country to country. The mechanism should include the responsibility and authority for development and management according to the country's fishery policy, which should be clearly and specifically defined. Fisheries development and management will involve (1) carrying out appropriate research, including the collection of the basic catch, effort, and biological data; (2) formulating, adopting, and enforcing regulations; and (3) the allocating of resources. This will be costly in terms of personnel and funds and may be difficult in the sense of finding politically acceptable solutions to difficult and complicated problems. However, without effective national mechanisms, it will not be possible to have an effective international mechanism.

Perhaps the simplest form of international mechanism is the bilateral agreement. Such two-country agreements usually deal with a specific fishery resource, but they could also deal with all the resources of a particular area. Under bilateral agreements, the information necessary for management decisions is usually developed by the fishery departments of two countries acting individually or in concert.

Although it is not generally thought of in this connection, the joint venture may be a form of bilateral agreement that is useful in management. In some areas of Indonesia, for example, the effort in the shrimp fishery is controlled through joint venture licenses. Although at the outset the optimum level of fishing effort is not known, it is being approached conservatively by initially restricting the effort by the joint venture company to a reasonably low level. The basic statistics are monitored by the government, and the amount of effort is allowed to increase as appropriate. The joint venture is usually thought of as an agreement between the government of a developing country, which supplies access to the resource, and an economically developed country which supplies technology, capital, and frequently markets. Both sides share in the profits by some agreed-upon formula. But the two partners could also be adjacent developing countries: for example, Thailand has recently shown great interest in the formation

of cooperative ventures with Malaysia and other neighboring countries. Thus, cooperative ventures between South China Sea countries may be a useful mechanism to further the interest of both parties within a general framework of management.

Multilateral arrangements, usually simply an extension of bilateral arrangements, are traditionally concerned with a specific fishery resource; they could be concerned with all or many of the resources of a particular area. But even in an area as small as the South China Sea, if each fishery resource management problem were to be taken up on an ad hoc basis, the proliferation of bilateral and multilateral agreements would soon exceed the ability of governments to cope with them. And this can easily be generalized to a worldwide basis; no government could cope with all the agreements needed on an ad hoc basis. Each agreement will customarily take two or three years, or longer, in preliminary preparation and negotiations, depending upon the importance and complexity of the problem. After the agreement is reached, each meeting held thereafter (usually annually) may require a great deal of preparatory work as well as attendant costs such as travel. Those attending the meetings and involved in such preparations within a particular government are the same people, and they have substantial other responsibilities. Since their numbers are small, it is impossible, because of time limitations, for these officials to be involved in more than a few arrangements at any one time. This suggests the need for a single multilateral agreement, which would deal with all of the fisheries management problems of the South China Sea involving two or more countries.

Are there any existing multilateral fishery bodies which might be able to assume this function? At present there are three possibilities. The Indo-Pacific Fisheries Council, formed in 1948, is an FAO commission for a region including, but not limited to, the South China Sea area. It seems unlikely that this council would be acceptable to the South China Sea countries as the mechanism for fisheries for at least three reasons. (1) There are eighteen member countries on the council, some of which are far removed from the South China Sea, and it is most doubtful that the countries of the region would wish to turn over their management problems to such a large and diverse body. (2) Over the years FAO has not been responsive to most of the requests addressed by the council to FAO. The reason given for this by FAO is that it operates on a finite budget and it has not been possible to accommodate these requests. (3) The council secretariat, which presumably would carry out management activities on behalf of the council, is part of the FAO staff; it is unlikely that the South China Sea countries would wish to vest this responsibility and authority with individuals

over whom they had at best only tenuous control. Similar reasons would apply to the UNDP/FAO South China Sea Fisheries Development and Coordinating Programme which is, in addition, likely to have too short a life-span to deal effectively with management needs.

The other existing multilateral body is the Southeast Asian Fisheries Development Center (SEAFDEC). This organization has a fishermen's training center in Thailand and a research training center in Singapore, while an aquaculture training center has recently been established in the Philippines. Its members include Japan, Malaysia, the Philippines, Singapore, South Vietnam, and Thailand. While SEAFDEC probably could not undertake the fisheries management responsibilities for the South China sea countries under its present membership, the possibility of it doing so in the future should not be overlooked. Of the three bodies mentioned, SEAFDEC at least comes closest to the requirement of having a responsive staff.

There are, in fact, no existing multilateral bodies which would be acceptable in their present form or could undertake the fisheries management responsibilities in the South China Sea. There is an urgent need for such a body, a South China Sea Commission if you will, to undertake such responsibilities. Formation of such a commission would involve consideration of membership, functions, staff, cost and funding, location, and organization work. Its membership should include all twelve South China Sea countries and political entities. It may be unrealistic to expect all of these countries to work together at this time, but full membership must be achieved if international management is to be effective. If there are distant-water countries, such as Japan, fishing in the area, then they should be included; but it might be desirable for such distant-water countries to attend the South China Sea Commission meetings as observers rather than as members.

The functions of the South China Sea Commission might include research and the formulation and adoption of regulations, their enforcement, and allocation. Research should be directed only toward topics relevant to management. The formulation of regulations would come about by interaction among the commission and technicians on the staff of the commission or on the staffs of member countries. Depending upon the organization of the commission and the amount of authority the member countries would be willing to delegate to it, regulations might come into force either upon their adoption by the commission staff or by majority or two-thirds vote of members. This would be the most efficient procedure because it could be reasonably rapid and it would be more difficult for special interest groups within countries to block agreements. If member

countries were not willing to delegate that much authority, then, following adoption by the commission, regulations would not come into effect until they had been adopted by the appropriate countries as specified by the commission. Regardless of how regulations come into force, it is almost certain that enforcement of the regulations would be by the member countries and not by the commission itself. This would be much less costly and, perhaps, much more palatable.

The formation of such a South China Sea Commission would need a period of preliminary preparation which would require funds and a sponsor. Support might come from the countries concerned, or possibly from the FAO or the UNDP; sponsorship would require a certain degree of neutrality. Another possible sponsor might be ASEAN (Association of Southeast Asian Nations). ASEAN members do not now include all of the South China Sea countries, but ASEAN has the clear advantage of being a purely regional organization with no outside obligations or entanglement.

The difficulties in resolving all these problems are clearly very great, but the realities of fisheries-resources management in the South China Sea indicate that there must eventually be some kind of regional fishery management. Continuation of the nonmanagement status quo will only lead to continued economic and biological disaster. The countries of the region must be able to act in their own self-interests on the basis of medium- and long-term gains as opposed to short-term gains. Indeed, the need for deferral of short-term gains in favor of medium- and long-term gains is one of the most critical and difficult problems extant in all fields of human endeavor today. As Crutchfield has said, "It must be remembered, however, that the long term is a series of short terms strung together, each of which must be politically acceptable."

[Extracted from Fishery and Resource Management in South-east Asia, pp. 4-58, RFF/PISFA Paper No. 7, a booklet published by Resources for the Future, Inc., Washington, D. C., 1976.]

Note: This booklet is one of a series, listed below, published by Resources for the Future on the fishing regions of the world. These can be obtained by writing: Resources for the Future, 1755 Massachusetts Avenue, N. W., Washington, D. C. 20036, USA. The

following article provides a global overview of the results of this research by the Director of the Project.

Series on Worldwide Fisheries

Francis T. Christy, Alternative Arrangements for Marine Fisheries: An Overview. RFF/PISFA Paper 1, 1973.

James A. Crutchfield and Rowena Larson, West African Marine Fisheries: Alternatives for Management. RFF/PISFA Paper 3, 1974.

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John C. Marr, Fishery and Resource Management in Southeast Asia. RFF/PISFA Paper 7, 1976.



LEFT: Purse-seine fishing off Palawan Island in the Philippines (Photo: FAO)

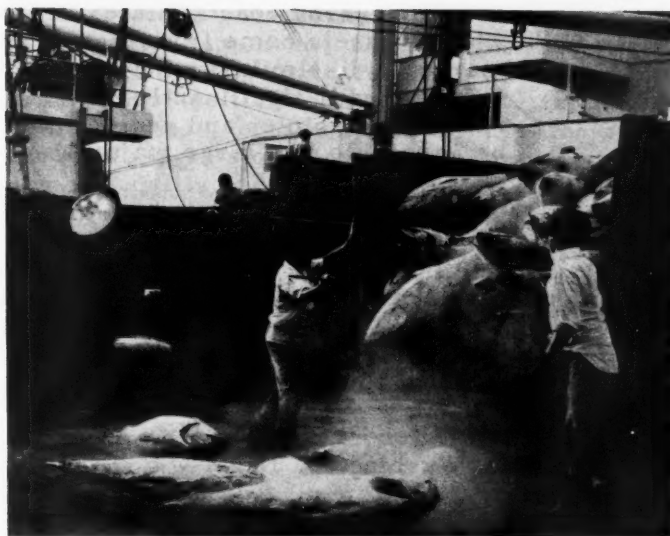


ABOVE: Fish Breeding operation in Java (Photo: United Nations)



LEFT: Raising milkfish in Taiwanese ponds. (Photo: Commission on Rural Reconstruction, Taiwan)

RIGHT: the transfer of tunny fish from truck to ship in Penang, Malaysia (Photo: International Labour Office)



Effective Fisheries Management with Regional Diversities

Francis T. Christy, Jr.

[The search for a uniform international fisheries regime at the United Nations Conference on the Law of the Sea will be impeded by the great diversity of conditions found in the different fishery regions of the world. The disparity among these situations is likely to set limits to the uniformity of general rules and principles that might be acceptable to the many nations participating in the Conference.]

As the delegates to the United Nations Conference on the Law of the Sea meet to consider alternative international regimes for the management and distribution of marine fisheries, they will be faced by the discomfoting fact that there is little, if any, uniformity in the major fisheries throughout the world. There is wide disparity in fishery situations with regard to a number of important factors - the characteristics of the stocks, the history of use, the nature of existing arrangements, and the interest and status of both the nearby coastal States and the foreign States whose vessels come from distant waters. This remarkable dissimilarity between regions and kinds of fisheries will significantly constrain the search for uniform principles and general conventions that will be agreeable to a large majority of the 150 nations concerned.

Despite these regional differences, there are certain fundamental characteristics that are common to all fisheries. One of the most important, of course, is the simple fact that fish swim and do not respect man-made boundaries. But not all fish have the same

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degree of mobility. Thus, there are four general classes than can be described: (a) where a fish stock falls entirely within the jurisdiction of a single coastal State, (b) where a stock swims within the jurisdiction of two or more neighboring or opposite coastal States, (c) where a stock swims both within the jurisdiction of coastal States and outside on the high seas, and (d) where a stock is found entirely outside national jurisdictions. Obviously, the classes are affected not only by natural conditions - such as the shallowness of the seas or the presence of upwellings - but also upon the boundaries of jurisdiction of coastal States. For example, we in the United States with our long coastlines view the sharing of fish stocks with quite a different perspective than do the fishermen of Ghana or the Ivory Coast, where coastlines are short and sharing of stocks is common.

Another, and related, fundamental characteristic of fisheries is that partial management is virtually tantamount to no management. Unless a stock is subjected to uniform rules wherever it occurs, the stock is likely to be vulnerable to depletion. If State A has no controls over a stock that is also found in State B, there is no incentive for the latter to conserve the stock because it would simply be reducing its own benefits in favor of its neighbor's. Without sufficient controls, the fishery will inevitably attract too many fishermen and vessels, and the costs of labor and capital will be much greater than they should be - that is, the same (or perhaps larger) value of total catch could be produced with fewer fishermen and vessels. But this control of fishing can only be achieved where the State, or some agent acting for two or more States, can exercise a high degree of authority.

The ability to exercise a high degree of authority is impeded by another fundamental characteristic of fisheries - the disparity among the goals for fisheries management. Some States may wish to use fisheries as a source of net economic returns, whereas others may desire greater opportunities for employment, reduction in the imports of protein materials, enhancement of maritime skills, etc. Where States sharing a single stock have different goals, agreement on the distribution of benefits presents considerable difficulties, and the choice of management techniques is complicated.

While these fundamental characteristics pertain to all marine fisheries, the ability to deal with them depends upon a large number of factors including the physical attributes of the stocks, the geographic boundaries of States, and the social, economic, and cultural patterns of the different societies. Some of the management problems that arise are illustrated here in summary description of those found in several fishery regions, and for one type of fish requiring

global management.

The North Pacific

Perhaps the most distinguishing characteristic of the North Pacific ocean region (here considered roughly the area north of Japan and Mexico) is the small number of States that have an interest in the fisheries. Until a few years ago, only four States - Japan, the Soviet Union, Canada, and the United States - had vessels operating in this region beyond narrow coastal waters. All four States are highly developed and have long traditions of fishing. A second important characteristic is that, like all other areas of high latitude, there are relatively few species of fish but large populations of each species. This, together with the high natural fertility of the region, has encouraged the development of specialized fleets concentrating primarily on individual species. In addition, the areas of high productivity cover extensive areas of the ocean, particularly in the Bering Sea where the continental shelf extends well beyond 200 miles. Third, the history of use in the region has been so great that most of the valued stocks have been fished to, or beyond, the point of maximum sustainable yields. (One possible exception is pollack, which now makes up about a fourth of the total marine catch of the region.) Even though fishing effort continues to increase, the opportunities for taking larger catches are quite limited.

The first international fishery conservation agreement of modern times - the fur seal treaty - occurred in this region and has been operating for more than 60 years except for a lapse during the Second World War. Since then many other multilateral and bilateral agreements and treaties have been made, and more than fifteen such agreements are now in effect. There are more agreements explicitly dividing up the resources in this region than in any other area of the world. Fur seal yields have been divided by all four States. Divisions of the yields from salmon stocks have been made between Canada and the United States; between Canada, the United States, and Japan; and between Japan and the Soviet Union. A similar array of distributional agreements are also in effect for king crab. This remarkable record of agreements, however, is being threatened by new developments and increased fishing pressures. As world prices for fishery products climb, so does fishing effort. But since the supplies are limited, the result is decreasing shares per unit of effort.

A second pressure - and one more difficult to alleviate - is the entry of new States into the North Pacific. In recent years, vessels from South Korea have started fishing in the region and there are clear indications that vessels of North Korea, Poland, and East

Germany will be entering. These new entries provide major threats to the continued viability of the current arrangements that are based on the assumption of closed access. For example, the "abstention" agreement, under which Japan abstains from taking salmon east of W. 175° longitude, would collapse if the South Koreans were to take significant amounts of salmon within this area. Similarly, sealing on the high seas by any of the new entrants which are not parties to the fur seal convention would make the present arrangement meaningless.

A third problem is that the agreements, even though large in number, are highly specific in nature and do not provide comprehensive coverage of all of the region's needs. Some of the newer fisheries, like those for pollack, saury and squid, remain essentially unregulated, while the other fisheries are the subject of complicated and time-consuming negotiations. There is no single forum that would facilitate coordination among the many separate ad hoc agreements or would allow rapid responses to the newly developing pressures.

In view of the particular conditions that exist in the North Pacific, it is difficult to see how the likely decisions at the Law of the Sea Conference would significantly alleviate the problems of the region. Two of the major participants - Japan and the Soviet Union - are strongly opposed to extended limits. But even if they should agree to this, it is unlikely to lead to dramatic changes in the present patterns of cooperation. For various reasons, the United States would be unwilling to exclude all foreigners from the vast area it would gain under a 200-mile limit. It could exercise more authority than it does at present, but would probably still continue to reach agreements through traditional means of negotiation. The most important requirement for the future management of North Pacific fisheries is that of creating an effective and comprehensive institution that will be able to incorporate, on a gradual basis, the plethora of present ad hoc arrangements and that will be able to respond expeditiously to the newly emerging pressures. But the UN Law of the Sea Conference is not likely to deal directly with the establishment of regional institutions.

West Africa

The fisheries of the East Central Atlantic are totally different, in almost every important respect, from those of the North Pacific. Instead of a handful of States with fishing vessels, there are vessels from about 40 different countries. About half of these are coastal States, all of which are low-income, developing countries. The 20 or so distant water States fishing in the area, on the other hand,

are almost all highly developed (exceptions being Cuba, South Korea, and Taiwan). Also unlike the North Pacific, the West African waters harbor large numbers of different species of fish, only a few of which are found in large populations. Furthermore there are wide differences in fertility along the coast, with rich upwelling areas off the sparsely settled desert regions, such as Mauritania and Namibia, but relatively unproductive waters off the coasts of some highly populated States, such as Ghana, Nigeria, and the Ivory Coast which are also countries from which fishermen actively explore the oceans adjacent to other countries. Indeed the accidents of geography tend to be perverse in this region, with poor resources off fishing States and rich resources off non-fishing States.

The development of the fisheries off West Africa has been extremely rapid, growing from 400,000 tons in 1958 to 2.6 million tons in 1970. More significant than the total growth, however, is its composition. Between 1960 and 1970, the catch by distant-water vessels from outside the region increased about five times, while the catch by the local coastal States rose only 80 percent. Most of the increase by non-African States has been through the use of large freezer-trawlers and factory fishmeal ships that are capable of catching and processing great quantities of fish without being dependent on nearby ports. Among these countries, the U. S. S. R. is the most active, followed by Spain, Norway and Japan. Among African nations, the largest catches are those of South Africa, followed by Angola, Senegal, Morocco and Ghana. The increase in fishing has been so large that many important stocks are now depleted or threatened by depletion. There is, thus, an urgent need for fisheries management and for the adoption of strict regulations and controls to prevent further waste. But while the general dimensions of the need can be defined, precise responses to the need are difficult to formulate because of critical lack of knowledge about most of the stocks.

Another critically important characteristic of this region is that regional cooperation on the management of fisheries is just in its infancy. The Committee for the East Central Atlantic Fisheries (CECAF) - the first and only international fisheries body for the area north of Zaire up to Morocco - has been in operation for only about seven years. For the region south of Zaire, it was not until 1971 that the International Commission for the Southeast Atlantic Fisheries (ICSEAF) was established. Both of these bodies have many members, including coastal and non-coastal States and developed and developing States. Both the size of membership and the disparity of interests are likely to impede, if not preclude, effective cooperation on management measures in these organizations, although they may be useful in the development of information.

The conditions in the West African fisheries may be significantly affected by, and may significantly affect, decisions at the Law of the Sea Conference. For example, proposals that would permit a coastal State to have exclusive rights only to the fish that its vessels can catch in its national zone of jurisdiction, while foreigners could fish for the rest up to some agreed total catch, would be virtually impossible to implement in this area. The lack of information, the large number of States with short coastlines, the migratory patterns of many species, the high mobility of foreign fleets, the disparity between factory vessels and primitive canoes - these and many other factors would preclude any meaningful calculations of degree of countries' utilization or capacity to fish within their national zones.

But the same factors also serve to create difficulties for the implementation of a fully exclusive 200-mile fisheries zone. Such a zone would permit the coastal States to control the large distant-water fleets - a control that is vitally important. It would mean that some stocks would fall within the authority of a single coastal State, thereby facilitating management, at least in principle. But a 200-mile fisheries zone would not resolve many of the other problems in the region. In fact, such a zone may encourage some coastal States to capitalize on their newly gained resources more rapidly than would be in their best interests and thus confront them with problems for which they are not yet prepared.

Among the problems facing the West African coastal States with a 200-mile fisheries zone, the most important would be that of gaining the information necessary to make regulations for management. While better information would be necessary under any regime, it would be solely a coastal State responsibility under the 200-mile fisheries zone approach. Another major problem associated with a 200-mile fisheries zone is that of enforcement. This is such an obvious problem that little need be said about it other than that costs can be reduced by cooperative arrangements among the coastal States. But even more difficult than enforcement would be the problems of allocation. The short national coastlines, together with the migratory patterns of many species, mean that many stocks would be found in two or more different jurisdictions if these are extended. This presents obvious difficulties for determining which State gets what share of stocks, or of the revenues collected from distant-water fishermen. In addition, as noted above, the pattern of richness of resources does not conform with the pattern of fishery interests. Certain African coastal States may wish to fish in the waters of others, but the others may find that the fishermen of far distant developed States are willing to pay higher fees than their African neighbors. And the allocation

problem is further complicated by the presence of numerous land-locked States desirous of getting some returns from the wealth of the seas.

In short, the problems of West African fisheries are inordinately complex in every dimension. A 200-mile exclusive fisheries zone may serve to facilitate the resolution of some of these problems but it may also exacerbate others. It is not so much that the other problems can be avoided - for they must be dealt with eventually in any case - but that the adoption of an international convention for a 200-mile zone may force the pace of the problems' development at a rate greater than can be accommodated by the rate of growth in regional cooperation.

Some Other Areas

There are, of course, many other regions and kinds of fisheries than those discussed above. In the Northwest Atlantic, there are presently over fifteen States engaged in fishing these highly fertile waters. The International Commission for the Northwest Atlantic Fisheries (which has had a long history) has recently taken heroic steps to resolve the problems through negotiations and the adoption of national quota systems. As in the North Pacific, this pattern of ad hoc negotiations is likely to continue, whether or not there is a general convention for a 200-mile limit. In the Northeast Atlantic, however, the West European states have generally been greatly affected by the actions taken elsewhere and by those of Iceland. It would not be surprising, therefore, to find the States of Western Europe adopting a 200-mile zone and creating a "European Pond" running from Gibraltar to the tip of Greenland and northeast to the Soviet line, excluding the Baltic and East European States. The West Europeans then might be able to maintain their present levels of total catch from all oceans by fish from the Northeast Atlantic alone.

In the Indian Ocean, fisheries are relatively underdeveloped. It has been estimated that the catch of marine organisms might be increased five and a half times over the 1970 level. The countries bordering this ocean do not generally have infrastructures satisfactory for maintaining large fishery industries, although this may change. Only 5 percent of the catch (tuna - see below) is taken by countries outside the region. The Indian Ocean Fisheries Commission, founded in 1967, with 31 members (19 in the region), has mainly collected information and facilitated development. Extension of national jurisdictions would do little to change the situation.

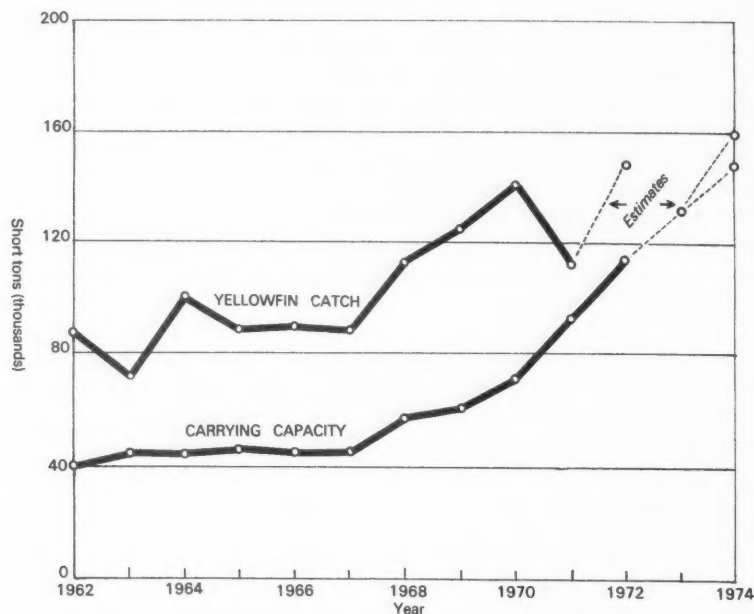
Global Tuna Fisheries

A separate discussion of tuna is included here because of its economic importance as a fishery and because its treatment on a regional basis would be inadequate. This is due to two significant characteristics. First, migratory patterns of most species of tuna tend to be very extensive - some stocks apparently covering whole oceans. Because of this, extensions of national jurisdiction, unless very great, would still leave many stocks in the international waters of the high seas during parts of their life cycles. Second, the migratory patterns of the tuna vessels are even more extensive than those of the stocks, since the larger, modern vessels are capable of traveling to all corners of the globe. Thus, regulations established in any one region have significant effects on tuna fisheries in other regions and other oceans.

Regulations will have to become much more stringent than they are at present because of the excessive pressures now being placed on the stocks of the six major species. The rapidly rising prices for tuna in the markets of the United States, Japan, and Western Europe (which consume more than 90 percent of the output) has stimulated a major growth in fishing effort. However, it is estimated that all but one of the six major species are at or near the point of full utilization in all three oceans - the Atlantic, Pacific, and Indian. Only skipjack tuna appear to afford some opportunities for increased catches, but these opportunities are limited. In less than a decade, the total capacity of the world's tuna vessels (assuming a conservative rate of increase in construction of new vessels) will probably be at or above that necessary to harvest the maximum sustainable yield for all six species in all oceans. And since fishing vessels will most likely not be appropriately distributed with regard to yields, there will undoubtedly be many areas where waste will be considerable.

International arrangements for tuna fisheries began in 1951 when the Inter-American Tropical Tuna Commission (IATTC) became operative. In 1967 the Commission put into effect a conservation control placing a total limit, or quota, on the annual catch of yellowfin tuna. This kind of control, while it is the most direct technique for conserving a stock, has very damaging economic consequences. It provides the incentive for each fisherman to build more, larger, and faster vessels in order to take as great a share for himself before the quota is reached and the season closes. In the case of the eastern tropical Pacific, the effect has been dramatic, as shown in Figure 1. The capacity of the fleet was fairly steady at about 45,000 tons until 1967. But between 1967 and 1973 it increased three times, to about 135,000 tons. Estimates for early 1974 indi-

Figure 1. Yellowfin Tuna Catch and Capacity of Fishing Vessels in the Eastern Pacific.



Source: Carrying Capacity, Salla and Norton, *op. cit.* Yellowfin Catch: *Annual Report of the Inter-American Tropical Tuna Commission*, 1972, p. 157.

cate further increases of 15 to 25,000 additional tonnage of vessels. It should be noted that the total quota and the catch was also increased after 1967, but catch only rose about 70 percent by 1972 compared to the three-fold increase in fishing effort.

Aside from the waste evident in the rapidly declining catch per unit of effort, the total quota control in the eastern Pacific has had global ramifications. The great increase in fishing effort led to a shortening of the season from the usual ten months to less than three months. As a result, the tuna vessels turn to other areas after the close of the IATTC yellowfin season, and many of them move to the Atlantic Ocean, where the International Commission for the Conservation of the Atlantic Tuna (ICCAT) is now considering regulations for the management of tuna in that ocean. Tuna

fisheries are also of concern to two other international bodies: the Indian Ocean Fisheries Commission and the Indo-Pacific Fisheries Council. Neither of these, however, has adopted any regulatory measures as yet.

The problem of distributing the benefits in an acceptable manner is obviously related to the management techniques that are selected. It is apparent that the major tuna-fishing States wish to adopt a system of national quotas that would tend to preserve, insofar as possible, the present pattern of distribution of catch. But this would not generally be acceptable to the many States that are rapidly enlarging their tuna fleets, starting new tuna fleets, or intend to do so in the near future. The dilemma that this poses is compounded by the fact that, as noted above, further increases in the number of tuna vessels will not lead to commensurate increases in catches. The new entrants, therefore, will not only tend to receive poor returns for their investments but will also serve to diminish the returns to all those presently fishing. Unfortunately, the proposals submitted to the Law of the Sea Conference thus far do not appear to offer much basis for compromise.

Global Institutions

The rapid developments in fisheries together with the possibility of considerable changes in the law of the sea raise questions about the future role of global fishery institutions. From the discussion above, several trends are significant. First, there is clearly a great expansion in the need for information. This includes information on the status of fish stocks, on their patterns of migration, the interrelationships between stocks, the economic values of the fisheries, the amount of fishing effort, the characteristics of fisheries labor, and many other economic, biological, and social factors. While there has always been a need for such information, the current situation is different in two respects. The first difference is that of urgency: these days, fisheries can develop so rapidly that stocks can be depleted within a few seasons, and may actually be damaged before the need for controls becomes apparent. The second difference is that extensions of jurisdiction - to the extent they occur - mean that coastal States must assume a greater burden of responsibility for gaining information than they have in the past.

Other significant trends have similar effects. There is a pressing need for more effective regulations and for systems that facilitate rapid adoption of regulations. The global mobility of much of the new fishing effort calls for coordination between different regulatory bodies throughout the oceans. Conflicts can be expected to

increase both in number and severity and will require improved methods for resolution. Finally, enforcement problems will become particularly difficult, not only if there are greatly enlarged areas of jurisdiction but also because of the likely attempts to circumvent the intent of regulations through such techniques as flags of convenience. There are, thus, greatly increased pressures for fulfillment of each of the major functions of fisheries management - research, regulation, coordination, conflict resolution, and enforcement. Of these, global fishery institutions have generally been restricted to the first - that of research. Some regional bodies play a role in the formulation and implementation of fishery regulations. Coordination of regulations between the regional bodies has not, thus far, been significant. Conflict resolution has generally been left to ad hoc negotiations among the interested parties. And enforcement is generally left to the coastal or flag States.

The realities of political constraints indicate that enlargement of the functions of global institutions is likely to proceed only by small increments. The most directly involved global institution is the Department of Fisheries of the Food and Agriculture Organization of the UN (FAO). Although it has devoted most of its efforts in the past to the development of fisheries, it has given increasing attention to management problems in recent years. It has fostered, sponsored, or otherwise stimulated the creation of several regional fisheries bodies and has held several conferences on management-related subjects. FAO clearly has a strong role to play in scientific research, and it may also take a stronger role in the formulation and evaluation of regulatory measures; but imposition and implementation of regulations will most likely remain the function of individual States or regional bodies. The function of coordinating activities between regional bodies is relatively new, arising from the development of highly mobile fishing fleets. FAO could play a valuable role in seeking greater coordination among the regional fishery bodies.

The role of FAO in fulfilling the function of conflict resolution is more difficult to foresee. While there are proposals before the UN Conference for creating machinery for the compulsory settlement of disputes, it is difficult to imagine that such proposals will be adopted. FAO might make use of its good auspices and other techniques for facilitating the resolution of certain kinds of conflicts. The function of enforcement of regulations is the one least likely to be fulfilled by a global institution such as FAO. These remarks are based on the assumption that stronger, more authoritative and more comprehensive global institutions are not likely to be adopted by the delegates of 150 States at the UN Conference. Even to achieve the enlarged functions described above is likely to take considerable effort as well as a cautious approach and a willingness to compromise.

In conclusion, it would appear that the decisions likely to be produced at the UN Conference will only have a limited effect on the problems of fisheries management and distribution. The adoption of an unconstrained 200-mile exclusive fisheries zone would tend to facilitate the resolution of some problems in some areas. Even in these situations, it can only be considered as a first step along a long path of extremely difficult problems that will be facing the different fisheries and fishery regions for decades to come. Nevertheless, the establishment of zones of national control is a necessary step toward the development of effective fisheries management, although it is far from sufficient as it will only be the beginning of the experience of national responsibility for many of the countries concerned.

[Extracted from "Disparate Fisheries: Problems for the Law of the Sea Conference and Beyond," Ocean Development and International Law Journal, Vol. 1, No. 4. Copyright © , 1974, Crane Russak and Co., Inc., New York City.]

Hidden Riches of Ponds

Staff of Tecnica Pesquera

[The conditions for growth of fish in ponds which are highly variable in size due to seasonality of rainfall can be quite favorable. This article describes some successful experiments in fish culture in an arid area of Mexico.]

Mexico's culture has always been linked with water in a dry land. Along with Coatlicue, the ancient Toltec goddess of fertility and death, Tlaloc, god of water, was the most powerful deity, for he was responsible for both drought and plenty. In every part of the country, water was worshipped and honored with special names and ceremonies by the prehispanic civilizations. The most beautiful Toltec paradise-after-death was an enormous marshland where one would swim, play, and sing for all eternity, accompanied by multi-colored fish and musical butterflies. Contemporary Mexico continues its battle for water in different ways and with different means, and water is still seen as a treacherous and ambivalent force which brings both catastrophe and plentiful harvests.

Mexico - a semi-desert country. The northern part of Mexico has less than 20 inches of annual rainfall, much of which falls in concentrated periods of time. Every year the rains leave tens of thousands of pools in ravines and depressions, many of which are of considerable size. These pools of water, be they temporary or permanent, could contribute in a substantial way to the supply of animal protein by the rural inhabitants, the poorest and most undernourished sector of Mexico's population. With the

Tecnica Pesquera is a Mexican journal specializing in fishery subjects. Translated from Spanish by Deborah H. Streeter.

help of simple technology and the development of organization, each pool could eventually be transformed into a small fish pond to supply many families with animal protein at an extraordinarily low cost, and with a minimum amount of labor.

Rosas' Experiments

While many biologists and technicians had recognized this potential earlier, it was Mateo Rosas, resident biologist at the limnological station at Pátzcuaro, who dedicated the past eight years to experimentation with the production of edible fish in the numerous rain ponds of the state of Michoacan. With little help from official institutions, Rosas selected nine bodies of water created by the rains in which he began to introduce, under a variety of conditions, eleven species of fish. Each pond had different characteristics, permitting Rosas to make comparisons and to draw scientific conclusions. The largest was about fifteen hectares following the rains, and the smallest was three hectares. While some were temporary and slowly dried up, others lasted the entire year varying in size in accordance with the rains and evaporation. The species he introduced were: charal, acámara, lobina, carp, "pescado blanco," bagre, catfish, three types of tilapia fish, and, defying all established facts, rainbow trout - *salma gairdneri* - a species considered adaptable only to crystal clear waters which have a high oxygen content and are very cold.

The drying-up process, an advantage. The work of Rosas, as well as that of other biologists, demonstrates that temporary ponds created by rains and floods are appropriate for fish culture. Prior to such research, it was generally believed that no temporary pond was suitable for fish production; but experiments showed that the transient nature of a body of water, far from being an inconvenience, presents several advantages for fishculture. Among these advantages, Rosas points out the following: (a) When the pond reaches its lowest level, harvesting is easy, as no fish can escape. The exact rates of mortality and growth rates of the fish population that was introduced can be determined. (b) The investment in fishing gear is minimal, which is important considering that the fish are caught by the poor rural inhabitants. (c) The processes of fish culture are facilitated by the elimination of predators, fertilization, collection of species, etc. (d) Because the temporary waters are rich in nutrients, the costs of production are reduced to very low levels. (e) Newly fallen rain waters present no problems of disease.

The Results of Opopeo

Although Rosas utilized nine bodies of water and eleven species, as mentioned above, the rain pond that provided the major part of

the conclusions and was considered the prototype was the one known as Opopeo. This body of water, formed every year when the rains fill a natural depression, lasts from nine to eleven months, depending on the intensity of the rains and droughts. It is located sixteen kilometers north of Patzcuaro, at an altitude of 2,200 meters in the region of Opopeo. After the rainfall, the pond reaches a maximum size of six hectares and will produce fish until it shrinks to one and a half hectares. The median temperature of the pond during the year is 18 degrees Centigrade, with a ph level of 7.2, and a concentration of oxygen of 6cc./liter. The pond has a muddy bottom and abounds with aquatic flora.

When the rains begin and the indentation in the earth starts to fill with water, an intense explosion of life goes on day after day in the depths of the growing pond, creating an optimum food chain for the species to be cultivated. Of the eleven species which Rosas initially introduced in his experiment, the only notable results were with carp (Ciprinus carpis) and with rainbow trout (Salmo gairdneri) which broke all records for growth of that species in fish culture stations. The other species introduced in the pond could not withstand the low temperatures and either did not grow or perished. The three classes of tilapia died, leaving the ichthyophagic fish such as the "pescado blanco" and the lobina without food.

The carp, however, found an ideal environment and had high rates of growth. Small carp, 3 cm. in length and 1.5 gr. in weight, introduced in June weighed more than 800 gr. and had an average length of 33 cm. ten months later. The most outstanding results came from the trout which were only introduced in Opopeo in 1971. In the beginning of 1972, a sampling of fish turned up trout 32 cm. long, weighing 350 gr. When these fish were introduced seven months earlier, they had measured only 4 cm. For the purpose of comparison, we may mention that in the principal trout station in Mexico, the rainbow trout in its first year reaches a size of 12 cm., from 18 to 24 cm. in the second, and only at the end of its third year does it measure 30 to 35 cm. - the same size that the trout in the Opopeo pond had reached in seven months! It is calculated that the growth of trout in the pond was 5 cm. per month, due to the abundant nutrients available. The above mentioned results clearly demonstrate the possibility of using ponds as miniature fish stations, self-sufficient and productive, managed and administrated after a certain training period by the rural population itself. Equally evident is the possibility that two competitive species, such as carp and trout, can co-exist and develop in the same body of water.

The carp and trout do not compete. With the introduction of carp and trout into the same pond, Rosas demonstrated that it is possible to produce abundant and cheap food, such as carp, which nourishes

the rural inhabitants, whether consumed fresh, smoked, or salted. Trout, smaller but more valuable, can be sold in the towns and cities nearby for high prices, to improve the meager incomes of the organized peasants. The co-existence of the two species in the same pond is due to the abundance of nutrients, and because of the different eating habits of trout and carp. Only towards the end of the life of the pond do the trout encounter difficulty in locating food, because they cannot see their prey in the turbid water. This difficulty is made worse by the constant movement of the carp close to the muddy bottom in search of food. It is therefore recommended that the trout be harvested 30 days before the carp, which can continue to be nourished due to the fact that they do not need to see their food in order to catch it.

The nets which are cast into the muddied and disappearing waters of Opopeo are pulled out full of fat carp and shining trout, demonstrating the hidden riches of each pond. What matters now is that this experiment should not remain merely an item in a bulletin of information or biological thesis. It is necessary to develop further the methodology for raising fish in a pond, and to organize a government program to assure that pond stocking becomes widespread in waterholes, rain pools, and in other bodies of water formed by nature or by man. Coupled with scientific and technical experimentation should be the education of the rural population in the production and consumption of fish. If not so complemented, these exciting scientific results will be a mere biological curiosity and material for publication, while thousands of ponds and hungry peasants will continue waiting for organization that is capable of bringing to reality the remarkable experimental finding obtained from a small pond in Michoacan.

[Extracted from "La Riqueza Escondida del Charco," Tecnica Pesquera, August, 1972, pp. 18-23, Published by Ediciones Mundo Marino S.A., Mexico 18, Distrito Federal, Mexico.]

The Ocean Food and Energy Farm Project

Howard A. Wilcox

[This article describes a novel proposal for growing seaweed on long lines under the surface of the ocean, with harvesting every three months of the seaweed and the fishes it may attract. The mechanism and the rationale for the idea are described, along with the processing and use of seaweed products. Some aspects of this proposal have been explored experimentally.]

Photosynthesis is the process by which solar energy is converted into energy stored in vegetation. The surface waters of the earth's oceans are abundantly supplied by the sun with the radiant wavelengths known to be required for the rapid growth of plants. Moreover, these waters possess copious quantities of the two major nutritional substances utilized by all photosynthesizers, water and carbon dioxide. The oceanic waters lying at depths of 1000 feet or more are generally cold and rich in nutrients (mainly potassium, nitrogen and phosphorus) required for high rates of plant growth. If these deep waters can be brought up toward the surface by artificial means, it seems likely that seaweeds adapted to the conditions of temperate waters can be grown in either the tropical or temperate latitudes. Thus these seaweeds can be utilized as relatively efficient converters of the radiant energy from the sun into the stored energy of carbohydrates, proteins and other vegetable compounds.

Processed or unprocessed seaweed can be a portion of the diets both of man and of land animals that are used by man for food. Further, some fish and

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invertebrates eat seaweed and the encrustations that grow on seaweed, and these aquatic animals can be harvested and used as food for man and his food animals.

Seaweed, being carbonaceous, can be processed by anaerobic digestion, fermentation or other processes, into methane plus a complete spectrum of useful petrochemical-type products such as fertilizer, ethanol, lubricants, waxes, plastics and fibers. Using seaweed as a source for these products has several advantages. First, the energy used to grow seaweed is solar energy, a renewable resource. Second, the use of seaweed proportionately reduces the need for fossil fuel and, hence, the ecological problems arising from the mining and other operations associated with fossil fuel.

Overall Concept

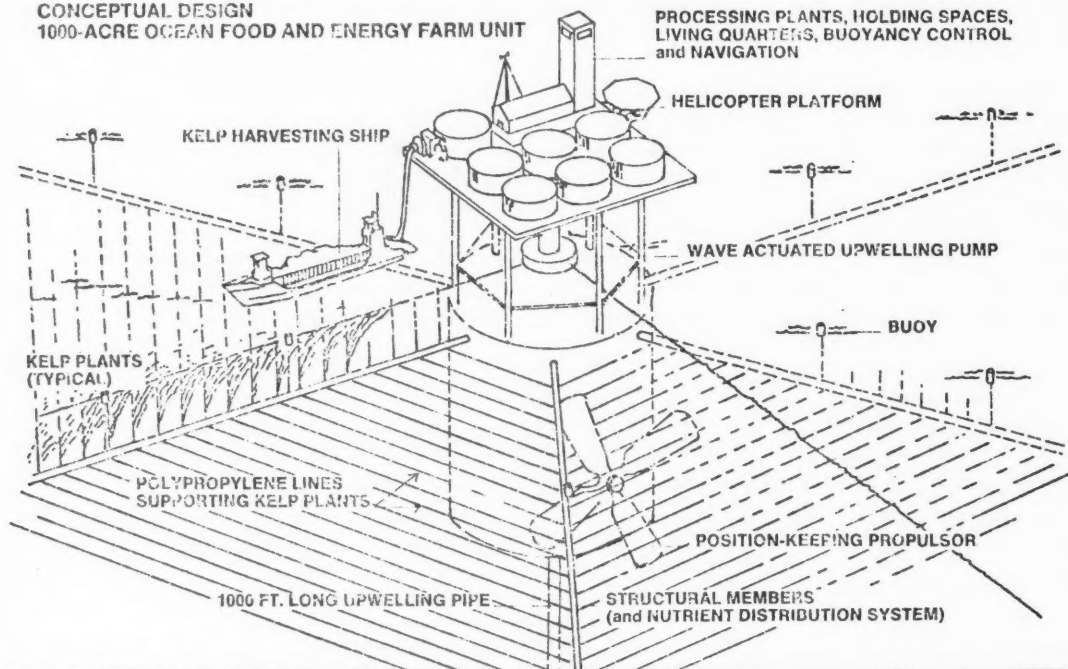
Two primary problems have prevented open ocean farming in the past. First, the natural bottom is generally so deep that sunlight cannot reach it, thus preventing the reproduction and growth of attached seaweeds. Second, the surface waters of the open ocean away from shore are in most areas almost devoid of nutrient content.

The concept of the Marine Farm Project is to culture rapidly growing and easily harvested types of seaweeds on lines in open-ocean or coastal nurseries, and then transport these lines to supporting structures embracing thousands of acres and lying 40 to 80 feet below the surface of the open ocean. The water surrounding the crop is to be "fertilized" and temperature conditioned by bringing up cool, nutrient-rich waters from a depth of a thousand feet or so in the ocean (see illustration). Additional nutrients can be supplied from the farm's processing plants or from shore-based sites if such should prove to be desirable.

A portion (or all) of these plants and associated animal communities are to be harvested periodically, and the crops of seaweeds and fish are to be taken to at-sea or coastal factories for processing. The seaweeds are to be converted into foods, fertilizers, methane and other fuels and industrial materials, at the processing facilities. Separate livestock and mariculture operations may be supported with feeds derived from the seaweed.

The technical feasibility of many of the processes required by the ocean farm concept are well established, so the major issue at present is economic feasibility. If the current experiments result in a well conceived and validly engineered system design, the economic feasibility of the concept can be evaluated in terms of the cost competitiveness of the ocean farm's products compared to similar

CONCEPTUAL DESIGN
1000-ACRE OCEAN FOOD AND ENERGY FARM UNIT



products from other sources at various time periods in the future. At the present time, it seems that the concept must eventually pay off, for as land-based food and petrochemical resources become increasingly costly, marine farming will necessarily improve in its relative economic feasibility.

Preliminary Selection of Giant Brown Kelp. Based on a survey of possible seaweeds, the "giant California kelp," *Macrocystis pyrifera*, which grows along the coasts of California, Mexico, and New Zealand, has been selected for initial ocean farm feasibility studies. *M. pyrifera* is one of the world's fastest growing plants, and the reproductive cycle is well understood as it has been cultivated in the laboratory and planted in coastal areas for several years. The fronds of this plant produce numerous blades and layers of these fronds lie along the surface of the ocean to catch the sun's rays. Nutrients are absorbed from the water by all exposed surfaces of the plants.

In nature, the life expectancy of each frond is about six months, after which the old frond dies off to make way for the new fronds grow-

Some of the products in which algin, the natural gum from kelp, is used today.

| <u>FOOD PRODUCTS</u> | <u>INDUSTRIAL</u> | <u>PHARMACEUTICAL</u> |
|-------------------------------|--------------------------|-----------------------------|
| Bakery Icings and Meringues | Water Base Paints | Dental Impression Compounds |
| Meat Sauces and Pepper Sauces | Wall Joint Cements | Toothpaste |
| Beer | Welding Rod Coatings | Surgical Jellies |
| Ice Cream | Corrugated Paper | Mineral oil Emulsions |
| Delicatessen Salads | Battery Plate Separators | Tranquilizing Tablets |

ing up from below. Therefore, the plant reproduces its own weight every six months or so. In the farm situation, however, the old fronds will probably be harvested every three months. Replanting of the field is not expected to be required after harvesting as the overall plants do not appear to exhibit natural aging, but plants may need to be replaced when torn away by storms, killed by disease or excessively damaged by fish grazing.

Though *M. pyrifera* is known to require cool water for survival, it is expected that the forced upwelling of cool, nutrient-rich deep water produced by the farm system will enable it to be cultivated even in tropical oceans. Assuming a spacing of some ten feet or so between plants, the farm will support about 436 plants per acre. Each acre is expected to yield about 300 to 500 wet tons of harvested organic material per year.

Kelp Support Subsystem. The concept calls for constructing a mesh which would be placed 40 to 80 feet below the ocean surface, and various mesh structures and positioning systems are being considered. An artificial upwelling system will also be needed, and although a final design has not been decided on, it is calculated that the system will require relatively little power - probably less than one horsepower per acre-foot of water per day. This power can probably be provided by harnessing wave or wind energy; once the total project is in operation, some of the farm's own energy yield could also be used to power the upwelling system if necessary.

Kelp Harvesting. The kelp canopy will be harvested by special vessels which will move over the farm and cut off the upper portions of the fronds. Some preprocessing, such as removal of water from the kelp, may be done on the ships before transferring the kelp to the processing plants. If fertilizers are provided in addition to (or instead of) supplying nutrients from deep water by artificial upwelling,

the harvesting ships may also be used to carry and dispense fertilizers. Kelco Co. of San Diego, California, currently uses special ships for their commercial harvesting of M. pyrifera, and adoption of their design will be evaluated.

Conversion of Kelp to Industrial Products. The intent of the Ocean Food and Energy Farm Project is to develop a variety of products from the harvested kelp to provide flexibility during system growth and market integration. Also, marketing a wide range of kelp products will reduce the cost of each. Kelp is already used in a number of industrial products, and this project will focus mainly on exploring the possibility of producing food for animals and people, methane gas (CH_4), ethanol ($\text{C}_2\text{H}_5\text{OH}$), fibers, and fertilizers. Processing will be geared toward a mix of products that provides a high return on investment.

It will be uneconomical to transport the wet kelp great distances, so some dewatering of the vegetation will most likely be done at sea. In fact, for remote ocean farms it will probably be desirable to have the whole processing subsystem on a sea-based platform. The processing subsystem can be powered by either environment power (direct solar energy, wave action or wind power), or by utilization of some of the fuel products of the facility. Current concepts for processing the kelp will be revised as appropriate, but right now it looks as if processing will be along the following lines.

The harvest will be prepared by passing it first through warm water to remove the surface coating of fucoidan, and then by coarsely chopping it. A weak solution of calcium chloride may be used to break down the cell structure to facilitate the removal of water and salts. A separation step may be used to segregate the electrolytes and carbohydrates, then the solids and carbohydrates will go through a hydrolysis process to further break down the polysaccharides, proteins, cellulose and bonded salts.

The soluble sugars pressed out after hydrolysis will be fermented to yield ethanol and a yeast feed. The primary solids pressed out after hydrolysis will go into anaerobic digesters where methane gas will be produced. A sludge, high in nitrogen, will also result, and this can be used as a fertilizer. Alternatively, the primary solids may be used directly for animal feed or processed by Bergius conversion, Fischer-Tropsch synthesis, or enzymic recycling (hydrolysis) to yield other products.

Conversion of Kelp to Human Products. In nature, kelp stands shelter and support abundant faunal communities, with the larvae of small animals attaching themselves to, and then growing on, the kelp. They obtain nutrition by filtering plankton out of the water. Fish, in turn, graze on the kelp, presumably digesting those encrustations,

but also obtaining some sustenance from the kelp vegetation or the plankton in the water. Such fish as opeleye perch and halfmoon naturally inhabit the coastal kelp beds off California.

In the ocean farm, the fish population should be easy to harvest. Open spaces will be left in the kelp fields, nets will be lowered into these areas, and the fish will be lured over the nets by chumming, use of an electric field, or use of flashing lights. The open ocean farms may be stocked with fish such as the opeleye and halfmoon, or it may be found that open ocean species will naturally collect in the cultivated regions.

Another approach for converting the kelp into food products is to feed the vegetation or its derivatives to fish, abalone, sea urchins, snails or other invertebrates in separate mariculture operations. Additionally, kelp derivatives can be converted to human foods by feeding them to land animals such as sheep and cattle. Further, a two-step conversion of kelp to human foods via insect larvae consumption followed by poultry or fish consumption may be practical and will be investigated.

Overall Development Plan

Tentatively, three project phases are planned for the Ocean Food and Energy Farm Project. The first phase, the proof of feasibility, is expected to take three to four years at a cost of some \$3 to \$4 million (dollars at 1974 values). During this phase investigators will prepare design concepts, demonstrate the feasibility of concepts, test subsystem models, place and study operation of two or three small scale farms, study problem areas, integrate subsystems, and perform operations and economic analyses.

The second phase, the proof of concept, is expected to take four or five years at a cost of about \$48 million. During this phase investigators will engineer and fabricate a culturing facility for small kelp plants, kelp farm structures, and a harvesting subsystem, and install two farms, one in the Atlantic and one in the Pacific, each of a size tentatively set at 1000 acres. They will also engineer and fabricate food, fuel and industrial material conversion facilities, and evaluate at least one year's operation of the two farms and processing facilities. The third phase, a full scale farm, estimated to take five to six years at a cost of about \$1.9 billion. During this phase investigators will enlarge culturing facilities, assemble a farm system tentatively set at 100,000 acres, and engineer and fabricate a correspondingly large capacity harvesting system and processing plants. A seven-acre experimental farm was successfully placed in exposed weather and sea-state conditions about 1000 yards off the northeastern tip of San Clemente Island, California, where the water is 300

feet deep. Between 100 and 150 *M. pyrifera* plants were taken from the nearby natural beds and attached to the farm, but no attempts were made to provide nutrients to the plants. Results indicated the kelp survival rates were very high and that the kelp reproduced well on all ropes and buoys of the farm. The natural nutrient levels in the ambient water were rather low, so both the natural beds and the farm showed relatively low growth rates. A combination of accidents, however, resulted in the total destruction of this farm unit late in January 1975.

Facilities have been prepared, reference data have been collected, and methane production has been achieved. Sheep, snails, abalone and fish have been started on kelp feeding trials, and results to date show sheep digestion efficiencies of 58 percent of the organic matter in the dried kelp - about the same as for the base ration composed of alfalfa hay, oat hay, barley and sodium phosphate.

The future. Assuming a two percent conversion efficiency for converting solar radiation into the stored energy of seaweed compounds, five percent conversion efficiency for the production of human food from the seaweed, and 50 percent conversion efficiency for the production of other products from the seaweed, the marine farm concept is "conservatively" projected to yield enough food to feed 3000 to 5000 persons per square mile of ocean area cultivated. At the same time it will yield enough energy and other products to supply more than 300 persons at today's U.S. per capita consumption levels, or 1000 to 2000 persons at today's world average per capita consumption levels. Since the oceans appear to contain some 80 to 100 million square miles of "arable surface water," this means that marine farms could conceivably supply a human population ranging from 20 to more than 200 billion persons, depending on the degree of affluence assumed. But before any such vast undertaking could be put into operation, of course, close attention and studies will have to be given to the possible problems of environmental degradation, societal upset, and legal/political difficulties. Some of these studies have already been started.

[Extracted from a supplement to *Calypso Log*, Vol. 3, No. 2, 1976. Published by The Cousteau Society, Inc., Los Angeles, California. The original article was adapted from an address by Dr. Wilcox to the International Conference on Marine Technology Assessment, Monte Carlo, October 1975.]

ENERGY AND AGRICULTURE



USERS OF ENERGY IN MEXICAN AGRICULTURE:
THRESHER, TRACTOR, AND TRUCK
(PHOTO: INTER-AMERICAN DEVELOPMENT BANK)

Energy and Agriculture: an Editorial Introduction

The three articles which follow are exploring an area which is receiving increasing scientific attention but which is currently in a state of flux and controversy among specialists. On the one hand, it is a field in which a great deal of scientific knowledge has been accumulated concerning the agronomy and the basic physics, chemistry and biology that are used for building blocks. On the other hand, the combining of knowledge from these different disciplines is so complex that wide differences in results can follow from the assumptions that are used.

Agriculture is both a user and a producer of energy. A subsistence farmer uses the energy of his family and his draft animals to grow crops; and crop growth also depends on the process of photosynthesis, which converts energy from the sun into vegetable matter (solar energy is the ultimate source for all man's traditional energy forms). The crops, in turn, produce energy in the form of food calories. In subsistence farming, much of this is recycled back into the farm: food for farm workers and animals, and for the wife and children whose needs must be met if the farm is to continue. In addition, support of the farm's activities requires other forms of energy: for cooking, and heating in cold weather, which may derive from the solar energy going into the growth of trees to supply wood; and for farm tools, houses and furnishings which embody energy from wood or other sources. If tools and cooking pots are of metal, then energy has been used to extract the metal and shape it, and to move it to the farmer; and energy goes into production of cotton or wool and the fabrication and transport of clothing. Even if all these products are made locally by handicraft methods, the labor time implies food inputs for workers' families, and the materials imply energy inputs of several kinds.

The energy accounting becomes even more complicated when one moves from subsistence villages to the many ramifications of modern commercial farming. Here a farmer will "export" energy (calories) to the market by crop sales, and "import" a variety of goods embodying energy inputs from distant factories. Many of these imports will be consumer goods, each with its own energy inputs too various to mention. More important for this analysis, the farmer's ability to export energy depends on his use of imported energy to raise the productivity of his land with such inputs as fertilizer (using natural gas- or petroleum-based nitrogen, along with other materials), farm machinery (metals, fabrication, etc.) and

the fuel to run it (gasoline or diesel oil). If the farmer raises cattle, pigs or poultry by modern methods, he will need specialized feed-stuffs (calories derived from acres of other people's cropland, or from fishmeal) to maintain his productivity - another chain of energy inputs and outputs leading to further inputs. All these inputs have made possible the gains in farm production which enable the world to feed its growing populations and raise living standards generally; and population trends as well as development aspirations point to a need for further accelerating this flow of energy into agriculture.

The recent "energy crisis" - high oil prices, foreign exchange problems, materials shortages - has dramatized the question of energy supplies. While some aspects of the "crisis" may have been temporary or accidental, there is no doubt that it brought the general subject forcibly to many people's attention around the world, and that it has stimulated a great deal of questioning of the assumptions about energy supply and a new search for energy alternatives. Specialists who had been thinking about these matters for years have found a newly enlarged audience, and novel ideas are being introduced. Agriculture is only one of many aspects of energy use, but one of the more important.

The basic problems in supplying energy to agriculture have a physical and an economic dimension. "Crisis" has brought attention to possible physical shortages of the mineral fossil fuels (oil, gas, coal) which have provided the rapid acceleration of energy inputs to date, and there is much debate on how long these resources will last. Without entering that debate, it is at least clear that such resources are non-renewable; and it seems likely that they will continue to cost more than in the past, whether or not higher prices are directly caused by current physical supply conditions. It seems improbable that agricultural productivity in the developing countries could be raised by a worldwide application of the high levels of fossil fuel inputs per acre, or per man, that are common in industrial countries; world supplies of these fuels would not permit such levels of use for many years under the most optimistic estimates. The next article by C. P. Timmer analyzes the economic constraints on the widespread introduction of fossil fuel energy into developing country agriculture under current and probable conditions. The second article by Gerald Leach documents the intensity of energy use that has evolved in modern agriculture, both in its methods of production and in the kind of products it supplies to meet the demand for food in industrial countries, and notes some implications.

Agriculture, however, is a producer as well as a consumer of energy. And the energy it produces is renewable in that it comes in large part from the vast current inflow of solar energy. This is un-

like the fossil fuels, which embody energy that originated in the solar inflow over millions of years, and which are not being created at anything like present rates of depletion. Thus, agriculture may be regarded as an energy source which could in time become more attractive as the costs of fossil fuels rise. It might provide the energy inputs for a growing agricultural sector, and perhaps even a surplus for other sectors. The somewhat unfamiliar technologies for doing this may have their first economically justified applications in the non-oil-producing developing countries, whose demand for food is great but whose purchasing power in world markets is limited. The third article, by Arjun Makhijani, presents proposals for using this kind of technology, illustrating its economic potential under conditions of an Indian village; the possibilities are not limited to India.

In these articles, as in others on the subject, frequent reference is made to units of energy required in various activities or embodied in various materials. Several kinds of unit are used, and although defined in different ways (as units of heat, mechanical work, electric power) they are interrelated. The joule, a unit of mechanical work, is related to the electrical watt: 1 watt = 1 joule per second; 1 kilowatt hour (kwh) = 3600 kilo-joules (kj). Another unit is the British thermal unit (Btu), a unit of heat, which is approximately equal to 1,000 joules (1kj). Calories are also used: 1 cal = 4.186 joules = .003968 Btus. (The calorie used for food energy is 1,000 times the "small calorie" just defined, and is properly termed a kilogram-calorie, or kcal, as opposed to the gram-calorie.) Large numbers of these units are designated as follows:

Kilo - = 1,000 units (e. g., kj, kcal, kw)
Mega - = 1,000,000 units (mj, megawatt)
Giga - = 1,000,000,000 units (gj)

Units of energy are also commonly expressed as equivalent (in Btus or joules) to that embodied in a quantity of coal or oil.

The energy efficiency of an activity or process refers to the percentage of energy emerging in a desired form (e. g., Btus in the kilowatt hours of electricity) compared to that used to produce it (e. g., Btus in the coal burned in electric generators).

Gordon Donald
Editor, Development Digest

Interaction of Energy and Food Prices in Developing Countries

C. Peter Timmer

[The economic relations involved in the introduction of fossil fuel inputs into agriculture in developing countries present some formidable obstacles to this important type of innovation. This article examines the supply and demand relationships, and notes some discouraging implications.]

Food is man's energy, but the production of that food requires energy inputs from outside the food system. Most of this energy input, even in highly commercialized agriculture, is from the sun and hence is "free." But this should not cause us to lose sight of the fundamental inefficiency involved in converting one form of energy into another. The secret is to find a cheap form to convert into a more expensive one. For agriculture, solar energy is the cheapest of all; but natural gas converted into nitrogen fertilizer, or petroleum converted into diesel fuel converted into rotary motion in an internal combustion engine converted into irrigation water, might also meet the cheapness criterion.

The criterion is economic, not technological. Whether it makes sense to convert five calories of fuel energy into only a single calorie of food, which is the energy input-output ratio calculated by the Steinharts for U. S. agriculture, depends on the relative price of food to fuel (among other things). This economic triviality has frequently been ignored in some of the more alarmist talk about the relationship between the "energy crisis" and the "food crisis."

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Some reputable technologists are seriously advocating the use of energy input-output ratios as the major factor in choosing agricultural production techniques (Pimentel, Lynn, McReynolds, Hewes and Rush). Such technological reasoning implicitly invokes an "energy theory of value" and leads inevitably toward labor-intensive, land-extensive agriculture and away from mechanized, irrigated, artificially fertilized agriculture. "For example, in Mexic[an] ax and hoe corn culture . . . a total of 1,144 hours of labor was required to raise a hectare of corn. Other than manpower, the only inputs were the ax, hoe, and seeds. By this method the yield in kcal of corn per input kcal was 10.13. The energy ratio is more than four times the U. S. average of 2.5." (Pimentel, et al., p. 6).

Mexican "ax and hoe" agriculture will not solve the "food crisis;" it is part of the problem. Modern, energy-intensive agriculture is the only hope for many of the world's present population and for most of its yet-to-be-born. Changing crop mixes, wider use of green manures, and more efficient use of energy in intensive agriculture are also possible. But the central point remains: to produce the food supplies needed for adequate nutrition in rich and poor countries alike, the only hope in the next few decades lies in energy-intensive agriculture.

This conclusion raises both technical and economic issues. First, is the energy available to convert low yield agriculture to high yield agriculture? Roger Revelle estimated the energy that would be required in a modernized, irrigated agriculture and food processing system in India. He included energy for the construction and operation of flour and sugar mills and cold storage plants but not energy for cooking and food preparation in households. Revelle's calculations show that the food energy obtained would be about twice the mechanical energy utilized, in spite of the large amount of energy used to pump groundwater for irrigation.

For the present average Indian diet of 2,150 kilocalories per day, 410,000 kilocalories of fossil-fuel energy per person would be required each year, equivalent to 55 kilograms of coal, costing at 1974 prices, \$2.50. That is about a fourth of the per capita use of fossil-fuel energy in India today. For a future diet of 3,700 kilocalories of primary plant materials and a population of 1.2 billion people, instead of the present 580 million, the total energy requirement for agriculture would be the equivalent of 95 kilograms of coal per person, or a total of 114 million tons per year. Estimated reserves of fossil fuels in India are between 100 and 1,000 tons per person. Hence if India relied on her own fuel reserves, enough energy would be available for a modernized agriculture for several hundred years.

Table 1 reproduces Revelle's calculations.

Table 1. Food-Energy Yield versus Mechanical-Energy Use for a Modernized, Irrigated Farming and Food Processing System in India

| | Millions of Kilocalories (per hectare) | (per ton of food grains) | Ratio of Mechanical Energy Used to Food Energy Produced |
|--------------------------|--|-----------------------------|---|
| Irrigation from wells | 3.75 | 0.585 | 0.167 |
| Chemical fertilizers | 3.01 | 0.469 | 0.134 |
| High yielding seeds | 0.15 | 0.023 | 0.002 |
| Plant protection | 0.05 | 0.008 | 0.002 |
| Farm tools and machinery | 1.05 | 0.164 | 0.047 |
| Fuel for machinery | 1.97 | 0.311 | 0.089 |
| Fuel for drying crops | 0.30 | 0.047 | 0.013 |
| Transportation | 0.18 | 0.028 | 0.008 |
| Storage and marketing | 0.05 | 0.008 | 0.002 |
| Food processing | 1.25 | 0.195 | 0.056 |
| Totals | 11.76 | 1.838 | 0.525 |

Source: Revelle, p. 165.

Note: The table assumes a harvest of 6.4 tons of food grains per hectare, equivalent to the average harvest of corn in Iowa. At present the average Indian farmer produces only about a ton of wheat or rice per hectare. Irrigation and fertilizers together account for about 65% of the energy that would be required directly on the farms to bring about the sixfold increase in yield.

Despite the apparent cushion of Indian fossil fuel supplies relative to the needs of a high yield agriculture, Revelle emphasizes that these provide only short-term promise. Development of the rest of India's economy, commensurate with a modernized agriculture, will also be energy-intensive. Fifty years from now India and most other countries will have to rely mainly on non-fossil-fuel energy sources - probably nuclear and solar - for the great bulk of their energy requirements. The pressing issue is what happens in the interim.

[Omitted from this extract are equations for a macroeconomic model relating the (low) price elasticity of demand for food in countries like India to the use of fossil-fuel-based inputs to agriculture for increasing food production, considering production functions and market-clearing equations. The results suggest that food prices will have to rise in the long run to maintain the profitability of energy-intensive farming under probable conditions when fossil-fuel prices rise.]

The model has direct relevance to the present energy-food situation. The feedback effect of low consumer response to changes in food grain prices, to the equilibrium prices for these foods, and hence to profitability conditions with respect to the use of high yield-producing energy inputs into food grain production, is too powerful to ignore. The essence of the message is that energy inputs must be profitable to use. If they are not, then relative food/energy prices must rise until profitability is restored.

Most energy applications in the food growing process, primarily in fertilizer and pumped irrigation water, are made prior to the time of harvest and sale. When energy prices go up, applications go down, and the resulting diminished harvest does not have an upward effect on food grain prices until several months later. The system is recursive. Since few farmers plan their input use with full knowledge and understanding of the recursive nature of the production-price formation system, several seasons will be needed before a new equilibrium can be reached after an exogenous energy price change disturbs an old equilibrium. Indeed, given the significant lag on the energy supply side with respect to price (primarily for fertilizers, but the search for oil is price responsive as well), and the great desirability of positive energy supply response to assure that convergence occurs mostly through greater food output when food prices rise rather than by reduced food consumption, the short run adjustment may last as long as five to eight years. This gives sufficient time for the fertilizer industry to put in place new investments in the face of a new price environment.

Different short-run supply responses for fuel and fertilizer should also be mentioned. Although total world fuel supplies may no longer be significantly price responsive in the short run, supplies available for agricultural use probably are price responsive. This implies an ability of agriculture to bid away supplies from other sectors, an ability that will come only through better relative prices for agricultural products.

Supply response for fertilizer is a considerably more complex issue. The fertilizer industry has been through several cycles of boom and bust, and there is a real danger that governments, corporate executives, and industry analysts will now seriously underestimate the future demand for plant nutrients because of past experience with overexpansion. Underestimating future demand by much will seriously prolong the present short-run disequilibrium and cause widespread hunger.

Part of the conclusion from the model that energy applications "must" be profitable stems from the *ceteris paribus* treatment of non-food-energy variables. Freeing them from this immobility alters the conclusion to some degree. In the demand equation, income and population growth can only add to upward pressures on food prices, other things being equal. Introducing these variables strengthens the conclusion that energy inputs into food production will require rising food prices because the demand function will be shifting outward.

A contrary effect is felt when other variables in the production function are freed. As the price of food rises to make energy inputs

profitable to apply, more intensive application of all other inputs becomes more profitable as well. The driving mechanism of the model is considerably weakened if substantial scope exists for expansion of food output through the application of nonenergy inputs. Indeed, if more acreage is available, more labor-intensive cultivation rewarding, better water control and use more feasible (without pumps), and so on, then the reliance on energy related inputs to meet the demand for food will be substantially weakened. The extent to which nonenergy options exist for raising food output will depend on individual national (and regional) circumstances. But even where they exist, food prices must rise to call them forth. The more general lesson is that food production must be profitable in the long run.

It is easy enough to say that food prices must rise relative to energy (and other input) prices so that growing food remains profitable. What is ignored in that statement is a consideration of the social and political costs involved in the process. Only the commercial farmer is fully protected on the income side in such a world, and even he will have to pay higher real food prices. Subsistence farmers who sell little food will benefit little from its higher price. The nonfarm poor are obviously the worst off. With no landholdings at their disposal to produce some of the high priced food for their own use, the nonfarm poor must find a means to buy their entire food requirements. This usually means cutting back on nonfood expenditures, but since many of the urban poor spend nearly all their income on food already, this offers little hope. A second alternative is to find additional sources of income. But the very logic of the model, that food prices must rise relative to other prices, will make this a frustrating effort. The final solution, grimly final in several countries, is a reduction in food intake and slow starvation for those already on the margin. The political implications, both domestically and internationally, are only now beginning to be seen.

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Energy and Food Production

Gerald Leach

[Food production in the industrialized countries is heavily dependent on inputs of energy from fossil fuels. The author analyzes these inputs with particular attention to the UK, and presents a wide range of data on the total energy used and how this relates to factors such as outputs, labor and land. He emphasizes the importance of low energy alternatives for Third World countries.]

Recently several studies have asked how much energy is needed for food production, and they have produced answers that are remarkable and rather perturbing. Broadly, they have shown that while most traditional farmers achieve high food yields per energy unit invested, the industrialized food systems of the West have raised food yields and quality and cut labor usage, but have done so by heavy consumption of - and dependence on - fossil fuels. Most developed societies now use 7 to 8 units of fossil fuel energy for each food energy unit consumed, or an annual 0.8 tons of oil equivalent per person.

These energy subsidies have helped transform working conditions and living standards in modern societies, especially on the farm. They are also a natural response to a period of high wages and cheap energy. Their emergence is easily explained. Yet they do raise several important policy questions for the future. Not least of these are whether recent trends in the energy-intensive food systems of the West need to be reversed, or can be without harm; whether they are a possible model for the

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developing world to copy; and if not, what energy-food strategies can do most for the energy- and food-hungry majority of the world's peoples.

The Energy Analysis Approach

This article presents a wide range of data relevant to these questions by focussing on the total energy used in food production and how this relates to other cardinal factors such as outputs, labor and land. Before doing so, three things must be said about the method and limitations of energy analysis. First, though it deals with a uniquely important resource, it is merely a descriptive science. It is a complement to, not a replacement for, economic or other valuation systems. Second, food production displays such wide variations of outputs and inputs due to climatic, soil, water, management skills and other factors that the energy analysis of food production is at present mostly limited to broad statements about averages. The average data presented here should be treated with this in mind. Third, and most important, energy analyses themselves vary widely in quality. Tracing all the direct and indirect energy inputs to a crop or national food production system is a formidably demanding task. Some approximations must be used, and some authors have been a good deal more approximate than others. This article relies heavily on the author's own study which examines the UK food system in detail with a consistent accounting method and set of data, and applies these to other food production systems.

The Input Range

Table 1 shows that energy requirements for a unit of food energy or protein vary by roughly 10,000 times as one spans the entire spectrum of food production systems. For the subsistence and hunter-gatherer communities of the first three entries the Energy Ratio (output/input) is consistently high, thus achieving a traditional aim of agriculture, which is to secure a net energy flow to man. With industrial systems much more energy is needed per unit of output, with animal products and sea fishing requiring consistently higher amounts of energy than crops, as one might expect. This last fact does much to explain why, for the total farm systems of the UK, USA and Holland, the Energy Ratio is always less than one and as low as 0.3. The Table also shows for the UK and Holland a strong trend towards greater energy intensity in agriculture in the last 20 years. When one includes the entire food production and delivery system to the point where food is sold in shops the Energy Ratios in developed societies drop to around 0.2, giving an annual fossil energy requirement of about 24 GJ or 0.56 tons oil equivalent per capita. In most developed societies a further 5-10 GJ per capita is used in transporting food to the home and in the home for cooking, refrigeration, etc. [Note: in this article the energy unit used is the joule. MJ = 1 million joules; GJ = 1,000 MJ, roughly equivalent to 1 million Btu.]

Table 1. Range of energy ratios for food production systems

| Farm gate or dockside | Energy out | Energy in |
|--------------------------------------|------------|----------------------|
| | Energy in | Protein out (MJ/kgP) |
| Chinese peasants 1930s | 41 | 3.6 |
| Tropical crops, pre-industrial* | 13-38 | 4-13 |
| Tropical crops, semi-industrial* | 5-10 | 15-80 |
| Wheat, UK 1970 | 3.4 | 42 |
| Maize, USA 1970 | 2.6 | 62 |
| Potato, UK 1970 | 1.6 | 96 |
| Allotment garden, UK 1974 | 1.3 | 58 |
| Rice, USA 1970 | 1.3 | 143 |
| Milk, UK 1970 | 0.37 | 208 |
| Eggs, UK 1970 | 0.14 | 353 |
| Poultry meat, UK 1970 | 0.10 | 290 |
| Shrimp fishing, Australia 1974 | 0.06 | 366 |
| All fishing fleets, Malta 1970-71 | 0.04 | 420 |
| Fishing, Adriatic 1970-71 | 0.01 | 1770 |
| Yeast on methanol 1974 | — | 170 |
| Yeast on N-paraffins 1973 | — | 195 |
| Winter tomatoes, Denmark (134 MJ/kg) | 0.004 | 14900 |
| Winter lettuces, UK (230 MJ/kg) | 0.002 | 26100 |
| All Agriculture UK 1952 | 0.46 | 251 |
| 1968 | 0.34 | 326 |
| 1972 | 0.35 | 315 |
| USA 1963 | 0.87 | 158 |
| HOLLAND 1950 | 0.91 | |
| 1960 | 0.53 | |
| 1970 | 0.30 | |
| Total food system to shop door | | |
| UK 1968 | 0.20 | 796 |
| USA 1963 | 0.22 | 616 |
| 1968 | 0.19 | |
| 1970 | 0.15 | |
| AUSTRALIA 1965-69 | 0.14-0.20 | |

* Pre-industrial systems have more than 95% of energy inputs in the form of muscular work by men or animals. With semi-industrial systems the proportion ranges from 10-95% but is usually 40-60%, the remainder being

fossil inputs mostly for fertilisers but with some machinery and fuels. All other systems shown are full-industrial, with muscular effort accounting for less than 5% of the total, and usually less than 1%.

Energy and Labor

An important consequence of the high energy ratios of 'primitive' farming systems is that labor requirements for food supply are not abnormally high, despite popular mythology. With an Energy Ratio of 25 a subsistence farmer need spend only two hours per day on average in order to feed a family of four with a combined food energy intake of 40 MJ per day. This figure is comparable to those of Western societies, where roughly 25-30% of household incomes are spent on food and drink.

Table 2 makes this comparison more explicit by comparing food energy yields per man hour of labor. Most non-industrial cropping systems achieve 10-20 MJ per man hour for raw food delivered to the home. With full-industrial crops this productivity soars to around 3000-4000 MJ per man hour of on-farm labor with food delivered to the farm gate. But these high outputs are then dissipated in two ways. Much of the crop is fed to animals, which reduces the productivity enormously. It is down to 50-170 MJ per man hour on most average UK livestock farms, for example. The second loss occurs when one includes all the other sectors of the food system. The total direct and indirect labor force in UK food production and supply is estimated at close to three million workers of whom less than half a million are farmers, and probably a further one million providing food and feed imports. On this total, the labor productivity is as low as 35 MJ per man hour.

Table 2. Food energy outputs per man hour of farm labour

| Agricultural system | Output (MJ/man hour) |
|--|-------------------------|
| <i>Pre-industrial crops</i> | |
| !Kung Bushmen, hunter-gatherers | 4.5 |
| Subsistence rice, tropics | 11-19 |
| Subsistence maize, millet, sweet potato, tropics | 25-30 |
| Peasant farmers, China | 40 |
| <i>Semi-industrial crops</i> | |
| Rice, tropics | 40 |
| Maize, tropics | 23-48 |
| <i>Full-industrial crops</i> | |
| Rice, USA | 2800 |
| Cereals, UK | 3040 |
| Maize, USA | 3800 |
| <i>Full-industrial crops plus animal</i> | |
| Sheep, cattle, pig and poultry, dairy farms, UK | 50-170 |
| Cereal farms, UK (small animal output) | 800 |
| <i>UK allotment garden, approx.</i> | 4.3 |
| <i>UK food system, approx.</i> | 30-35 (all labour) |

This is a notable figure in view of the frequent claims that modern methods allow one farmer to feed 60 or more people. These methods depend on, have allowed, and indeed largely caused the vast social changes - including urbanization and the factory system - which have put large distances between the field and the mouth in every sense and greatly swelled the ranks of non-farm workers in the food system. In fact the average worker in the overall food system in the UK feeds only 14 to 16 people - a figure that is typical of the middle to upper range for preindustrial farmers when one counts actual working time.

This comparison does not allow for important differences of climate, food quality, supply reliability, and working conditions.

The UK Farm System

A greater insight into food-energy relationships can be gained by looking at the changing patterns of one country. Here I examine the UK, where modern farming methods and a modern industrial-urban food supply structure have evolved to a greater extent than in most countries. As late as the 1920s, UK farming was a pre- or semi-industrial system, with only 10,000 tractors compared to 410,000 today and an average fossil energy input of a mere 100-150 MJ per hectare year compared to 9,000 MJ in 1970. Only 6% of farms had a power supply, and their combined consumption was less than 1% of present levels.

The transition to full industrialization occurred very rapidly and mostly in the 30 years since World War II. Figures 1 and 2 give a rough guide to the scale and pace of these changes. In England and Wales (Figure 1) the number of farm horses declined precipitously, releasing 10% of the total farmed area for food production; whole-time farm workers fell in 50 years from nearly 700,000 to 260,000; and the tractor population rose to about 350,000. At the same time, while crop yields rose to roughly double their 1900 level (Figure 2), consumption of energy-intensive chemical fertilizers soared.

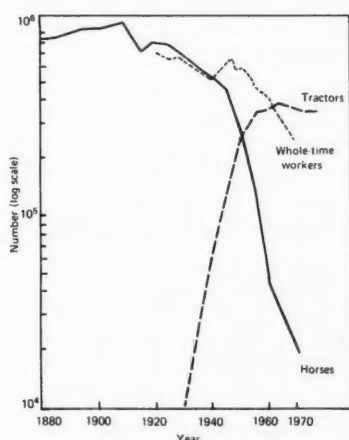


Figure 1. Number of farm horses, tractors, and full-time workers in England & Wales, 1880-1973

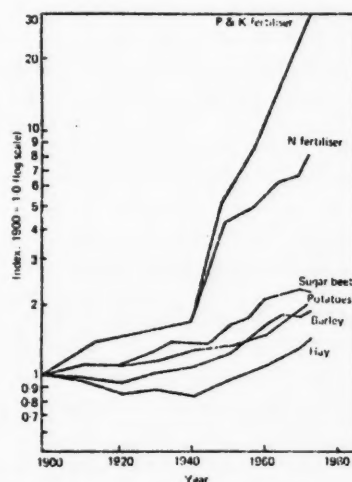


Figure 2. Fertiliser tonnages and crop yields in the UK, 1900-1972

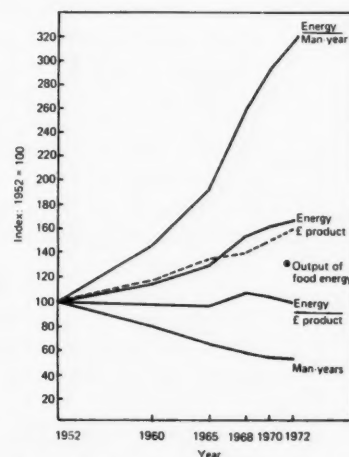


Figure 3. Energy, manpower and £ product, UK agriculture 1952-72

The effects on energy consumption were substantial. From a very low level at the start of the century, by 1968 the energy input to UK farming had risen to 378 million GJ, equal to 4.6% of UK primary energy consumption in that year. Of this total, 108 million GJ represented fuel and power, 82 was fertilizer, 84 was for machinery, buildings, transport and various services, 53 for agricultural imports, and 51 went into food industries to process animal feedstuffs. For this investment, among others, farming delivered 130 million GJ of food energy and 1.16 million tons of protein for human consumption - enough to feed exactly half the population in terms of calories and 62% in terms of protein.

From 1952 to 1972 total energy input to food production increased by 70% from 241 to 410 million GJ, nearly twice as rapidly as gross UK fuel consumption which rose 40% in the same period. Figure 3 shows how this increase of energy related to other factors of production. The value added or "£ product" of agriculture rose (in real terms) more or less in step with energy inputs, so that energy used per pound sterling remained roughly constant. Since the cost of fuels and power declined in real terms, it became more and more profitable to substitute energy for other basic inputs, especially labor. However, while value added increased substantially, nutritional food outputs increased far less: during the period the output of edible food for humans rose by 30% in terms of energy and 35% in terms of protein. Consequently, the Energy Ratio declined substantially from 0.46 to 0.35, while the energy to produce a kilogram of protein rose from 251 to 315 MJ.

But the most notable changes were in the substitution of energy for manpower. By 1972 each full-time farm worker was backed by a direct energy input of 502 GJ or 11.6 tons of oil equivalent per year. Counting all part-time workers, directors and the like reduces this to about 180 GJ per man year. Even this lower figure puts agriculture, on this measure, well into the category of heavy industries - in the UK the direct energy per man-year is about 130-140 GJ in engineering and 310 GJ in motor vehicle production. Equally significant, the marginal energy cost of replacing labor appears to have soared. In the early stages of farm mechanization it often took only 10-20 MJ of energy to save one hour of labor, but by 1965-70 this quantity had risen to around 230 MJ. According to S. S. and C. E. Steinhart (*Science*, Vol. 184, 1974, pp. 307-16) the equivalent figure for the USA during the same period was about 720 MJ per man hour saved (this is not corrected for higher food outputs per hour).

The overall food system. In a developed urban society such as the UK, farming accounts for only a fraction of the total energy required for food supply. Food has to be transported, processed, packed, stored and sold in shops, and in the UK it has to be imported in large quantities. The energy flow for the whole UK food system

to the shop door for 1968 is estimated to be nearly 1300 million GJ, for a population of 55 million, or 15.7% of national energy consumption. The per capita consumption of 23.6 GJ is almost identical to an estimate of 23.7 GJ made by Hirst for the USA in 1963, when the food system accounted for 12% of the national energy budget. The Energy Ratios were also much the same at about 0.2 (see Table 1).

Nor is this a viable system for all people for all time. Copied on a global scale it would demand prodigious quantities of energy – 4000 million people each consuming 23.6 GJ per year of fossil fuels in order to eat (let alone cook) gives an annual fuel bill of 2185 million ton oil equivalent or 40% of global commercial fuel consumption in 1972. This figure might be reasonable if other efficiencies were especially high. We have already seen that they are not for labor usage, nor are they for land. Table 3, which summarizes the energetics of the UK food system, shows that the overall biological energy efficiency is only 0.02% while food outputs are, at most, 10.6 GJ per hectare, or only 6.7 GJ per hectare counting rough grazing. Each Briton depends on at least 0.71 hectare for food – ignoring all imports of food and feedstuffs. This is little less than the global average of 1.1 hectare per person counting crop land, permanent meadows and pastures.

Why are these efficiencies so low? The overwhelming reason is the high proportion of animal products in the diet and in farm outputs. The UK farm produces exactly equal amounts of dietary energy in the form of animal products and of crops fed directly to man (see Table 3). Yet while the latter are grown on 1.55 million hectares, animal production requires 10.25 million hectares of crops and grassland and approximately 1.52 million hectares for imported feedstuffs. Thus the crop sector is seven to eight times more efficient in its use of land to provide food energy than is the animal sector. This is a minimum estimate since it ignores a further 6.65 million UK hectares of rough grazing suitable only for animal raising.

The Global Challenge

In the underdeveloped world the imperatives of agricultural development are to increase food yields, quality and reliability – and hence the wealth of agricultural communities – without high costs, severe environmental impacts or reduced employment. Carbon copies of Western methods are mostly irrelevant or at worst dangerous. New strategies are needed, and in these energy plays a peculiarly important role.

Consider Table 4 which shows how energy is supplied to six "prototypical" villages in the Third World. These are farming

Table 3. Summary of energetics of UK food system, ca. 1968

| Biological flows | | 10 ⁶ GJ per year |
|-------------------------|---|-----------------------------|
| A. | Solar radiation incidence | 610 000 |
| B. | Primary production harvested from plants | 1 116 |
| C. | Imports of animal feed | 104 |
| D. | Edible farm output: crops | 65 |
| | animals | 65 |
| E. | Total edible farm output | 130 |
| F. | Food energy consumed by population | 261 |
| G. | Primary conversion efficiency (B/A) | 0.18% |
| H. | System efficiency [E/(B+C)] | 10.7% |
| I. | Overall efficiency (G x H) | 0.02% |
| J. | Food energy self-sufficiency (E/F) | 50% |
| K. | Food protein self-sufficiency | 62% |
| L. | Food energy output/ha of crops and grass in UK | 10.6 |
| M. | L including rough grazing | 6.7 |
| Industrial energy flows | | |
| N. | Energy input to agriculture (and % all UK) | 4.6% 378 |
| O. | Energy input to food system (and % all UK) | 15.7% 1 300 |
| P. | O counting home-related energy use (22%) | 1 820 |
| Q. | Energy ratio of agriculture (E/N) | 0.34 |
| R. | Energy ratio for whole food system (F/O) | 0.20 |
| S. | R including home-related energy (F/P) | 0.14 |
| | | GJ per year |
| T. | Energy input (O) on <i>per capita</i> basis | 23.6 |
| U. | Agricultural input/ha for crops and grass in UK | 30.7 |
| V. | U including rough grazing | 19.5 |

communities. Almost all the human and animal energy is used in food production, including irrigation, and much of the wood, dung and crop wastes are used for cooking. Several striking points emerge:

- 1) When cooking is included, energy used in the food system is comparable to that in the West. With these fuels, per capita annual consumption for cooking is about 5-7 GJ compared to 1-2 GJ for modern gas stoves and three GJ for electric stoves in the USA.
- 2) The cooking fuels are precious resources - dung as fertilizer, crop wastes as manures or animal feeds, and wood as ecological capital. Growing pressures on fuelwood throughout much of the Third World, where annual consumption is often 1-1.5 tons per person per year, is creating ecological threats through indiscriminate tree felling with subsequent erosion and creation of deserts.

- 3) Energy supply is overwhelmingly from food or biological sources (the Mexican village excepted) with extremely low efficiencies of use. With draught animals the conversion of fuel to useful work is about 3-5% compared to 25-30% for a tractor. Similarly the conversion of fuels to useful heat in cooking is about 5% compared to 20-25% in a modern gas or electric stove.

Table 4. Energy use in six Third World villages

| Village | Gross energy (GJ per capita) | | | | |
|---------------------|------------------------------|------------------|--------------|-----------------|-------|
| | Wood, dung, crop wastes | Commercial fuels | Human labour | Draught animals | Total |
| Mangaon, India | 4.2 | 0.2 | 3.2 | 7.9 | 15.5 |
| Peipan, China | 21.1 | 3.6 | 3.2 | 5.3 | 33.2 |
| Kilombo, Tanzania | 23.2 | — | 3.2 | — | 26.4 |
| Batagawara, Nigeria | 15.7 | 0.05 | 3.0 | 0.75 | 19.5 |
| Quebrada, Bolivia | 35.4 | — | 3.5 | 10.6 | 49.5 |
| Arango, Mexico | 15.1 | 38.9 | 3.8 | 7.6 | 65.4 |

Source: A. Makhijani (see next article) converted from million Btu to GJ units.

In all such communities, adequate power to work the fields and to pump irrigation water (where available) is crucially important for raising yields and avoiding the ravages of drought - and hence for increasing the wellbeing of people. Normally this power is not available because the efficiencies of using energy are so low and the total available energy is limited. Apart from the costly solution of providing more energy from outside by commercial fuels and electrification, the single most urgent need in the food-energy equation is to find cheap ways of harnessing more effectively the energy that is locally available, i. e., using it with higher efficiencies. This in turn means providing storable energy with high thermodynamic value - for example, gas or liquid hydrocarbons rather than dung, wood and vegetation.

It is becoming increasingly obvious that bioconversion and the direct use of solar power provide the way out of this trap. The skills and technologies are simple, and the fuel sources are widely available, forever renewable (with care) and ecologically inoffensive

(with care). Perhaps above all, they are ideally suited to small-scale, self-help, decentralized development which is so relevant to the great majority of the world's poor who still live in scattered rural communities. Consider what the conversion of organic matter to biogas (approximately 60% methane) would mean in general terms for such villages [described in the next article].

A similar argument applies to other renewable energy sources which provide concentrated fuels or power. These include liquid fuels obtainable from plant matter by fermentation, destructive distillation or pyrolysis for powering machines such as cultivators or small tractors; electricity from biogas or 'fuel forests'; conventional solar panels to provide hot water and space heating in colder mountain regions; and simpler versions of solar-electric devices such as that proposed by the Meinels of Arizona University for concentrating sunlight onto pipes, storing the energy in molten salts or rocks, and extracting it as required (day or night) to drive turbines to provide electricity at overall conversion efficiencies as high as 25%.

The development and diffusion of energy devices of these kinds throughout the rural areas of the Third World is an enormous challenge. Perhaps above all the challenge is to the broadness and subtlety of our vision. Many of these devices have been costed by the conventional calculus of economics and have been found either to be wanting or only marginally attractive compared to more conventional technologies. The question is whether the conventional calculus, with its high rate of discounting the future and its failure to catch many of the most relevant factors in its net, is the most appropriate guide. No one has yet thoroughly explored the multitude of consequences and transformations that developments of this kind could bring about - not least on food production, on rural incomes, on personal wellbeing and self-respect, on the invigoration of village life, and on the mass migrations to the exploding cities of the Third World - in short, on the whole development process.

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Fuel for Agriculture in the Third World

Arjun Makhijani

[A basic need for the growth of Third World agriculture may be supplied by the use of crop residues and manure to make methane gas for fuel in small village biogas plants. This article examines the economics of such plants under current conditions in an Indian village, which appear favorable, and describes the great potential for this technology in agricultural development.]

Poor countries need all the energy they can get, as cheaply as they can get it. Development policy in most underdeveloped countries has bypassed the effective use of noncommercial fuels from energy sources other than oil or coal, partly because cheap oil was available but also because technology has been borrowed from the industrialized countries which have failed to develop and tap these sources of energy. We wish to explore alternative technologies and to examine, in view of the large increases in the prices of oil and fertilizers in 1973 and 1974, the economics of decentralized energy systems in providing fuel and electricity to Third World villages from locally available sources.

Among the decentralized technologies, we have devoted the most attention to the conversion of organic materials to gas in village biogas plants because it appears to be an economical way to provide fuel and fertilizers for Third World villages with a great, but so far almost untapped, potential. The basic raw materials for producing fuel and fertilizer in biogas plants, i. e., crop residues, increase as agriculture becomes more productive. In fact,

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the agricultural sector has the potential of taking care of its own energy needs and having some left over for domestic uses, transport, or other uses.

Electric power from fossil fuels. The usual way of supplying electric power for rural places is to generate electricity in a large central plant and send it through an extensive transmission network to a wide area. The cost of electricity in the village, from large-scale oil or coal-fired thermal electric generating plants, is the standard against which alternatives are usually measured. It will be the measure here.

Two important values must be established before realistic choices for development can be made. These are the capacity factor and the interest rate for invested capital. "Capacity factor" is the proportion of a power plant's capacity which is actually in use, on the average, over a period of time. The capacity factor in villages is very low. In India, the average annual rural capacity factor is about 10 percent (800 kwh/kw). This compares with the 40 percent which is characteristic of urban demand in India and many other underdeveloped countries. The effect of such low capacity factors is to greatly amplify the capital cost per unit of electricity generated and to reduce the relative importance of variable costs. Capital-intensive power supply systems will therefore be at a disadvantage unless rapid development takes place simultaneously with electrification, and as power becomes available its use for such purposes as irrigation for multiple cropping rises in such a way as to increase the capacity factor.

The interest rate for capital is also an important determining factor in the choice of the technology to be used. A commonly accepted rule of thumb is 12 percent; this figure does not include depreciation or inflation. While this interest rate is higher than rates that are sometimes used to justify development projects or capital-intensive schemes, we use it to give appropriate weight to the shortage of capital prevalent in most underdeveloped countries.

Table 1 shows the capital and other costs of generating electricity in central power stations and distributing it to rural places, using coal-fired generating plants. Using India as an example, several critical factors determine whether centralized or decentralized generation is more economical: the capacity of the distribution system, the capacity factor, and the distance of the village from a main transmission line. The cost of electricity delivered to a typical electrified village (that is, a large village) in India is around 8 to 10¢ per kwh. This is much higher than the 2¢ per kwh or so actually charged rural customers in India because only the cost of the distribution system is included in calculating what the charge should be. Thus the users of electricity in Indian villages are receiving a continuing large subsidy from the government.

Table 1. Cost of Centralized Electricity Supply in Coal-Fired Generating Plants in India (U. S. Dollar equivalents)

| | | | |
|---|---------------------|-----------------------|--|
| Capital cost of central fossil fuel generating station per kw | 250 | | |
| Transmission cost per kw (20% attributed to rural line) | 50 ^a | | |
| Rural distribution cost if village is 8 km ^b from line, \$25/km/kw | 200 | | |
| Total capital cost per kw | 500 | | |
| Annual interest and depreciation per kw, 15% | 75 | | |
| | 15% capacity factor | 10% capacity factor | |
| Interest and depreciation per kwh | 6.5¢kwh | 9.4¢kwh | |
| Approximate fuel and maintenance cost per kwh | 1¢ kwh | 1¢ kwh | |
| Total cost | 7.5¢kwh | 10.4¢kwh ^b | |

^a Assuming that a 100 kw powerline goes to the village.

^b At 16 km from the transmission line the total cost becomes 14¢/kwh; at 24 km it becomes 18¢/kwh.

It is almost impossible to generalize accurately about the cost of electricity generated in small village diesel sets. Installation and fuel costs will vary from village to village. On the whole it appears that electricity from decentralized small-scale diesel generators is more expensive than power from central stations if the village is reasonably large (more than a few hundred people) and less than about 10 km from a high-tension transmission line. Figures corresponding to the 7.5 - 10.4¢ per kwh range in Table 1 would be 11 - 13¢ per kwh.

Biological materials as an energy source. Biological materials are the most important immediately viable decentralized energy source for electric power and for mechanical power as well. They can be used directly as fuel or converted to other forms. The economics and technology of using wood and agricultural wastes directly to raise steam for power production are not very favorable. Capital costs are high and the efficiencies of small plants are low (10 percent). Steam engine generating plants with a capacity of a few hundred kilowatts cost \$600 to \$800 per kw. Given the low capacity factors en-

countered in rural areas, electricity costs of 10¢ to 20¢ per kwh may be expected even if we ignore fuel costs.

The destructive distillation of wood in the absence of air (pyrolysis) is an ancient technology which may be an economic approach to providing fuel for small towns, though not for most villages, since the plants required are too large and the costs of pyrolysis are sensitive to the size of the system. Pyrolysis of wood (or other organic matter such as newspapers and food wastes) produces charcoal, a medium Btu gas (10,000 to 18,000 Btu per cubic meter compared to about 36,000 Btu for natural gas) and combustible liquids with around 70 percent efficiency. We are not aware of any recent attempts to evaluate this old technology for use in poor countries in view of current high oil prices. However, there are a few indications that the economics of wood pyrolysis might be attractive. First, wood is currently used in China as a tractor fuel, and was used even when prices of oil were low. Second, wood pyrolysis was phased out in the industrialized countries because of cheap oil and the relatively high cost of labor (associated primarily with the collection and transportation of wood). Neither of these conditions applies today to poor countries.

Biogasification is perhaps the most important technology for converting biological material to more useful forms of fuel. It can be put to widespread use in the near future, its economics appear favorable, and it produces organic fertilizers in addition to fuel. In this process complex biological materials are broken down by anaerobic bacteria (that is, bacteria that work in the absence of atmospheric oxygen) to simple organic compounds which are in turn converted to methane and carbon dioxide. Of the biological materials encountered in nature, only mature wood appears to be largely resistant to breakdown; the plant material and manure that comprise most agricultural residues are broken down.

A biogas plant consists of digestors (the receptacles in which the biogasification takes place), facilities for storing and slurrying the residues, and sometimes facilities for grinding the residues and drying the residuum from the digester. A system large enough to supply a village reliably should include two or three digestors and gas storage. The digestors produce an intermediate Btu gas (20,000 Btu/cu. m.) consisting primarily of methane (55 to 65 percent by volume) and carbon dioxide. Standard techniques for the removal of carbon dioxide and small amounts of hydrogen sulfide can produce methane, a high Btu gas similar to pipeline quality natural gas. (The Monfort Company, in Greeley, Colorado, U.S., plans to build a large biogas plant on its cattle feedlot and sell the purified gas to a natural gas pipeline company.)

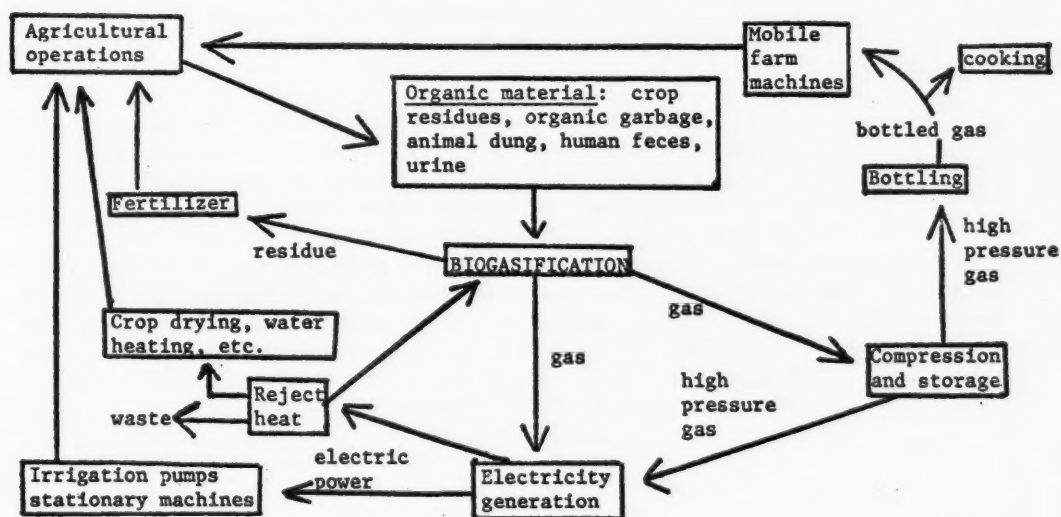
From the point of view of returning nutrients contained in biological materials to the soil, biogasification has an advantage over ploughing

in manure since the fertilizer is already in usable form, in contrast to manure which must usually be allowed to decompose in the soil for many days before planting. This is especially important with multiple cropping, since prompt planting permits more crops.

The use of biogas as a basic energy resource for villages had been recommended by the Fuel Policy Committee of India and it is now the object of special study of the National Academy of Sciences of the U. S. as a promising source for supplying energy to villages in the near future. Much of the work on the development of small biogas plants has been done in India, and since 1973 there has been a resurgence of interest in applying this technology to meet some of India's fuel and fertilizer problems. Several thousand small biogas plants have been built on individual farms. Currently, most of this gas is used for cooking rather than for agriculture. The basic resource - agricultural residue - is found wherever there are agricultural communities. The technology for converting these residues is also well enough understood for us to make a preliminary economic evaluation and a comparison of the costs of village electrification schemes based on biogas with those based on central station generation.

A possible rather advanced village scheme is outlined in Figure 1. An important feature of this scheme is that farmers are paid for the residues which they deliver. The price paid for the residues will vary from region to region depending largely on the ease of collecting the residue, the suitability of the residue for gasification,

Figure 1. Schematic Diagram of Village Biogas-Electricity Scheme System



and whether the wastes are currently used for other purposes such as cooking. Prices might vary from about 70¢ per million Btu of animal manure in North Indian villages where dried manure is used for cooking fuel and is scarce, to 20¢ per million Btu for crop residues or dung where these are abundant and are not presently used.

Paying for raw fuel on the basis of energy content will favor the delivery of crop residues, for they have a much higher energy value per ton than wet manure which, in its fresh state, has a water content of up to 80 percent. This has an important advantage but may also create a problem which must receive simultaneous attention. The advantage is that it is more efficient to gasify crop residues directly rather than feeding them to animals. But if sales of crop residues deprive cattle of their fodder, the result could be a reduction in the number of cattle (which may or may not be desirable), or still feebler cattle, or more overgrazing of pastures. The price for the fuel for the biogas plant should ordinarily be based upon the prevailing wage rate and the fuel and fertilizer value of the material; but it may have to be modified and varied from one year to the next depending on the availability of crop residues to take account of the important indirect effects on the village economy.

The gas the plants produce which is not used immediately for electricity would be compressed and stored. Bottled gas would provide the fuel for farm machines and, if necessary, for cooking. The compressed gas could be taken from storage and used when needed at times of peak demand for irrigation pumping, tractors, etc. Such a fuel is obtained economically at consistent high capacity factors. Compressed gas storage is relatively inexpensive in both economic and energy terms. The large amount of waste heat produced in the generating plant (about 75 percent of the total input) would be relatively high grade heat with a temperature of about 300°C. Part of this heat could be used to regulate the digester temperature. The rest could be used for crop drying, producing raw sugar, heating water for domestic uses, and so on.

The residuum of undigested materials which leaves the digester is an excellent organic fertilizer. It could be returned to the land either mixed in the irrigation water or as a semi-solid, after dewatering. In some places such as North India and Tanzania, this return of nutrients would mean a large increase from present use of fertilizer. In others where composting and manure are already used, such as China and South India, it would reduce the organic fertilizer losses inherent in composting; but the principal benefit from biogasification would be the fuel produced. Digester residuum does not attract flies which spread many diseases, and digestion at the right temperatures also suppresses the pathogens in human feces.

The safe disposal of human excrement (feces and urine) is one of the most important measures for the prevention of disease in Third World villages. The pathogens that human excrement harbors cause a variety of serious diseases such as cholera, typhoid, schistosomiasis, amoebic dysentery, and enteritis. These pathogens can be destroyed by uniform heating to 60°C for 30 minutes to one hour. In anaerobic digestors that operate in the intermediate temperature range 25°C to 40°C, the pathogens may take several weeks to be destroyed. However, organisms may well be completely destroyed in the 40° to 60°C range which would apply to properly managed compost piles, or to anaerobic digestors appropriately heated, for example, with waste heat from a biogas-electricity generating plant. The amount of heat required would be about equal to the amount of gas generated from the feces. There would be no net gain in fuel from processing the human excrement; the gains would be in improved health and in the output of fertilizer. Composting of excrement, which may be cheaper but more difficult to manage, would achieve the same result. Apart from the significant health benefits, large quantities of fertilizers, particularly fixed nitrogen, can be recovered from human excrement (particularly urine which has a high nitrogen content). Building latrines could be a profitable proposition on the basis of the value of the recovered fertilizer. Some approximate calculations for the costs and value of output in such a scheme were made for Indian villages by the Khadi Village Industries Commission. If the operation is conducted on a nonprofit basis, an annual payment could be made to each family for using the latrines.

Decentralized energy systems have often been dismissed on the grounds that maintenance would be difficult. Electricity use in Indian villages tends to decline over time, even when the electricity comes from a centralized source, which points to a lack of local maintenance. Much of the capital investment for agricultural development must be made in the villages, in tubewells, pumps, motors, irrigation channels, and so on, whatever the source of fertilizers or power. If these facilities are not maintained, then no program can achieve the goal of agricultural progress. But, if the personnel to service these essentially decentralized aspects of agricultural development are trained and available, then the added problems of biogas plants and decentralized electricity generation should not be difficult.

Energy availability for biogas. To estimate the energy from wastes available for power generation, we must know the energy content of the basic resource - the agricultural residues. Accurate estimates would require the following information: (a) a breakdown of crop production in individual villages; (b) the agricultural residues associated with each ton of harvested crop; (c) the amount of crop residues consumed by animals; (d) statistics for the animal

population, including both numbers of animals of each type and the average weight of these animals; (e) data relating to manure production and its quality with due regard to feeding conditions normally encountered in villages, and the ease of collection of the manure. None of this information is available in any general and authoritative form. We have attempted preliminary estimates of the available energy residues in six selected villages in India, China, Tanzania, Nigeria, Mexico and Bolivia which are representative of many agricultural systems in the Third World.

Estimates of the "residue coefficients," that is, the ratio of the weight of dry matter residue to recorded harvested weight at field moisture, have been computed for important crops by the U. S. Department of Agriculture and others. For most crops they fall between 1.0 and 2.0; for some they may be as high as 3.0 (cotton, soybeans), and for others less than 1.0 (sorghum, sugar cane); they vary considerably with plant varieties and harvesting practices. In the six representative villages, the annual averages for harvested crops, the volume of dry crop residues, and the energy content of the latter were estimated for each village. Counting crop residues not eaten by the animals present in these villages, and assuming that 80 percent of this mass is collectable for use, the quantities range from 700 up to 27,000 tons per year. Similarly, annual kilograms of manure production from the cattle, horses or donkeys, pigs, sheep and goats, or poultry were estimated for each village. Nitrogen content was estimated, assuming levels from 1 to 2 percent for most animals but 6.3 percent for poultry, and assuming 70-80 percent manure collection (30 percent for sheep and goats). If these residues and manures were converted to biogas at 60 percent efficiency, the village totals for energy production have a wide range from 500 to 13,000 million Btus per year - the largest for the Mexican village which has extensive irrigation and large crop residues. Dividing by number of inhabitants, we find energy availability from this method is 3-4 million Btus per capita average a year in three villages, with 5, 8, and 30 million in the others. If the fertilizer residue from biogasification were used in agriculture, it would supply nitrogen at rates of 18, 20, 25, 33, 65 and 68 kilograms per cultivated hectare. [Supporting tables for these calculations are found in the original book.]

In all cases, the existing energy use for irrigation and farm machines in these villages is lower than the potential available from biogas. As for fertilizers, except in two cases the potential quantities are several times the amounts of nitrogen fertilizers that are now used. For the development of agriculture in such villages, however, it will be necessary to think in terms of increasing productivity by use of improved seed varieties and multiple cropping, which will greatly increase the need for fertilizer. The available nitrogen

fertilizer from manure varies a good deal and is often not sufficient to allow the use of high-yielding seed varieties. Other sources of nitrogen would be necessary, and phosphorous, potassium, and other trace minerals must usually be purchased. Fortunately, these mineral fertilizers are less expensive than chemical nitrogen; unit prices are lower, and the amounts needed are usually less. Planting several crops each year will certainly require the use of chemical nitrogen, although the animals supported by crops could be increased.

Cost of a biogas-electricity system in the village of Mangaon, Bihar, India. We now compare the costs of a biogas-electricity system under conditions in the Indian village of Mangaon with the costs of conventional rural electrification projects in India which are based on centralized electricity generation. In comparing these costs, one should take into account as a deduction from cost the value of gas for cooking and of the fertilizer returned from the system to the land. In Mangaon this nutrient value is now lost, as virtually all collected manure is burned as fuel. We have assigned a value of \$400 per ton of nitrogen content. This is a conservative value, above the \$300 government price of urea in 1973 but well below official prices of over \$500 in 1974 and the still higher prices paid by farmers to intermediaries. Gas used for cooking fuel is valued at \$2.00 per million Btu.

Table 2 shows the capital costs for two biogas-electricity schemes, one with provision for supplying gas for cooking, the other without. The cost shown in column A indicates that if half the biogas produced is used for cooking, the capital costs of the electric power from biogas is only slightly less than that for a centralized scheme (assuming a main transmission line 8 kilometers from Mangaon). This is not only because of the costs of distributing and using cooking fuel but, more importantly, because only half of the gas produced can be used to generate electricity. The capital cost per kilowatt of the biogas-electricity scheme with no gas for cooking (column B) is about half that of the centralized scheme.

The annual costs of the two schemes are shown in columns A and B of Table 3. With the conservative assumptions that are used in calculating these costs, the cost of electricity produced in the scheme in which biogas would be distributed as cooking fuel is slightly higher than the cost of the centralized scheme shown in Table 1. For the second case the cost of electricity would be considerably lower: 5.8¢ per kwh compared to 7.5¢ per kwh or more. One of the conclusions to be drawn from Table 3 is that, contrary to current practice, biogas should not be used for cooking unless it is necessary.

Table 2. Capital Costs of Biogasification-
Electrification System in Mangaon (in 1974 Dollars)

| | With 50% Cooking Fuel A | Without Cooking Fuel B |
|---|----------------------------------|---------------------------------|
| Biogasification plant ^a | 8,000 | 8,000 |
| Gas plant auxiliaries | 1,000 | 1,000 |
| Land cost | 1,000 | 1,000 |
| Gas storage and compression ^b | 1,500 | 1,500 |
| Cooking fuel distribution cylinders and gas stoves ^c | 8,000 | — |
| Electric generator with reciprocating gas engine and switchgear at \$160/kw installed ^d | 12,000 | 22,500 |
| Construction supervision and training | <u>1,000</u> | <u>1,000</u> |
| Subtotal: capital | 32,500 | 35,000 |
| Interest on capital during six months' construction at 12% | <u>2,000</u> | <u>2,000</u> |
| Total | 34,500 | 37,000 |
| Cost per kw | \$460 | \$265 |

^aWe assume two digestors, each producing 140 cubic meters of biogas per day. The gas production in columns A and B is the same. Exclusive of the energy use in the biogas plant, the digestors will produce about 2 billion Btu of fuel per year.

^bStorage for 50 percent of annual production of unscrubbed gas.

^cColumn A assumes all 200 families in the village use methane for cooking, \$6,000 for cylinders, \$2,000 for stoves. Column B assumes zero use.

^dBased on mid-1974 quotation from a manufacturer in the U. S. A. and includes approximate shipping costs. In the scheme with cooking fuel we have a 75 kw generator (col. A); without cooking fuel the entire output of the gas plant goes to a 140 kw generator.

Table 3. Annual Costs for Two Biogas-Electricity
Schemes for Mangaon, India (in 1974 Dollars)

| | A With Biogas for Cooking Fuel (50%) | B No Cooking Fuel Pro- vision |
|--|---|--|
| 1. Annual interest and depreciation ^a | 5,700 | 6,100 |
| 2. Residue collection at \$2/ton fresh manure | 2,600 | 2,600 |
| 3. Local labor and maintenance ^b | 1,300 | 1,300 |
| 4. Market town services | 500 | 500 |
| 5. Labor for distributing cooking fuel ^c | 300 | — |
| 6. Gross annual costs | 10,400 | 10,500 |
| 7. Credit for cooking fuel sales ^d | -2,000 | — |
| 8. Credit for fertilizer ^e | -2,400 | -2,400 |
| 9. Total credits | -4,400 | -2,400 |
| 10. Net annual operating cost | 6,000 | 8,100 |
| 11. Annual electricity generation at 12 5% capacity factor | 75,000 kwh | 140,000 kwh |
| 12. Cost per kwh | 8.0¢ | 5.8¢ |

^aInterest rate 12 percent. Biogas plant (digestors) depreciated at 3 percent per year, other capital at 5 percent per year.

^bAbout one man-year, plus parts.

^cOne man-year for distributing gas.

^dCharge for biogas used for cooking \$2.00 per million Btu.

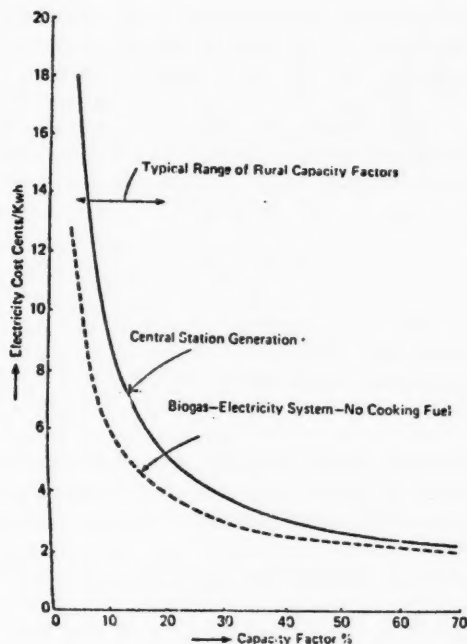
^eCredit taken only for fertilizers available in the solid portion of collected dung - four tons of nitrogen at \$400 per ton, two tons of phosphorous (P₂O₅) at \$250 per ton, and two tons of potassium (K₂O) at \$150 per ton.

The cost of manure collection in Table 3 is high because it is assumed that only animal dung is used in the biogas plant. Crop residues contain about five times as much energy per ton as wet dung, so that the cost per million Btu of input to the digester, and hence the cost of electricity, would be lowered as more crop residues are used (that is, as more food is grown and surplus crop residues become available). The net cost of electricity depends critically on the value of the fertilizer content of the residuum in the biogas digestors. In Table 3 we have assumed that only the nitrogen in the solid portion of the dung is available. This gives an annual production of four tons of nitrogen, two tons of phosphorous (P_2O_5), and two tons of potassium (K_2O). Proper preparation of household stables (or common stables) with straw, sawdust, and other cellulose litter will absorb the urine. This would increase the nitrogen available to seven tons per year, with smaller increases in phosphorous and potassium. The nitrogen can be further increased to 10 tons of nitrogen per year if latrines for collecting human excrement are installed and widely used. When animal urine is included, the cost of electricity in both cases is lower than that of the centralized system. The costs of electricity and biogas are lowest when human excrement is also used: they could be reduced to 5.3¢ per kwh in column A and 4.4¢ per kwh in column B.

Introduction of electricity. The foregoing discussion of costs is based entirely on current patterns of electricity use. These are wasteful of capital. Rapid development will require that capital be used much more effectively than it has been previously, the more so for countries that are hard pressed to pay for food, fertilizer, and oil imports. In India, rural electrification and irrigation account for almost all the government's rural capital investment. If the cost of these programs is to be reduced so they can be offered to more people, it is imperative to improve the capacity factors as this will make electricity cheaper from whatever source, central or local, and from whatever fuel. Figure 2 which shows a graph of electricity cost versus capacity factor illustrates this principle, and shows the enormous reduction in electricity cost achieved when improvement of only a few percent is made in the prevalent low capacity factors.

In most cases it would be preferable to delay the introduction of electricity until a sufficient capacity for its use has been built up. Irrigation pumps and farm machines could be powered by internal combustion engines (the same ones for both purposes so far as possible). This would reduce the capital cost of providing energy for agriculture considerably, and current costs per unit of useful energy obtained directly from an internal combustion engine are much lower than the corresponding costs for electricity because the intermediate generating step is eliminated. As small industries in the village develop, electricity could be introduced.

Figure 2. Variation of Electricity Cost with Capacity Factor



Electricity is desirable for irrigation and for powering stationary small machines because electric motors are more reliable and need much less maintenance than internal combustion engines. After electricity is introduced, the internal combustion engines could be used for transporting produce to market towns as well as for some stationary applications such as sugarcane crushing. Electrification is also important for the positive psychological effect it has on people's attitudes, for establishing a modest communications system, and so on. From an energy point of view, using local energy resources to generate electricity has advantages both over centralized generation and over the use of fuels in many dispersed internal combustion engines. The waste heat, which is usually 300°C or higher, can be put to many beneficial uses, such as crop drying, local manufactures, or water heating. The greater the variety of uses for electricity (and waste heat), and the more evenly they can be distributed over the year, the higher will be the capacity factor and the lower the unit capital cost.

Fuel for farm machines. Even more than with rural electrification, a principal problem with supplying fuel for farm machines is not so much the price of oil relative to other sources but the foreign exchange shortage. Thus in Punjab, India, which supplies the country with most of its surplus wheat, many tractors and irrigation pumps lay idle in 1974 because farmers could not get enough oil. In relatively large villages (say, 500 or more people) where gas for cooking is not required, biogas would be a cheaper fuel than oil for fueling farm machines and small trucks or tractors with trailers. For example, a farm machine used 10 hours a day for 15 days will require about 10 million Btu of fuel, assuming an average power output of 5 horsepower. Diesel fuel delivered to the village will cost over 50¢ a gallon (about \$4 per million Btu), and gasoline will be even more. Petroleum costs for such an operation are likely to be about \$40, much of this in foreign exchange. Fuel from a biogas plant can be provided for \$25 or less, including the cost of the gas containers and compression equipment. In villages smaller than 100 people, the costs of the compressors and other equipment needed to bottle the gas may make oil the cheaper alternative even at present high prices, particularly if there are only a few farm machines. The relative economics in such cases would also be affected by the location of the village since transporting oil to remote places is quite expensive. But if there are many small villages within a radius of 10 or 20 kilometers, biogas would probably be the cheaper alternative since common maintenance facilities could be provided.

In sum, the discussion of energy needs and the calculations presented here indicate that the fuel and fertilizer needs of villages and market towns in the Third World can best be met by a combination of the centralized and decentralized approaches, rather than by the centralized approach alone which has been used so far. The potential of rural sources of fuel and fertilizers in spurring agricultural growth seems great. Pilot projects are needed to determine more accurately the costs and problems of implementing such decentralized projects in different areas of the Third World.

Illustration of Growth Potential

As a specific illustration of the concepts presented above, we examine the potential for agricultural development under conditions in Mangaon, India. Because of its poverty, and the scarcity and low productivity of land in that region, the resource constraints are greater than they would be in most regions. The village population is 1,000. Annual production, on 282 cultivated hectares with some 300 draft animals, totals nearly 600 tons. Crops, in order of tonnage, are: sugar cane, rice, maize, wheat and barley.

Mangaon as it is today - with its one crop per year, less than one

ton per hectare economy - has a potential for agricultural production, labor and land productivity, and number of productive jobs that is immensely greater than in the past. Water resources are abundant; the land is fertile; there are plenty of fish in the rivers. To explore that potential, let us examine whether in theory (that is, institutional constraints aside) it is possible for Mangaon to grow enough food for its own people and export half of the food it produces. Let us define "enough food" as 2,500 kilocalories and 70 grams of protein per person per day. The results of our calculation should not be interpreted literally, for they are simplified and represent only one hypothetical example of what could be achieved within today's technical and economic constraints.

The principal constraints we consider, other than the fixed amount of agricultural land, are these:

1. No source of energy is available from outside the village. This is related to the foreign exchange shortage which limits oil imports, and to many diverse problems with India's coal industry.
2. No more than 15kg/ha of chemical nitrogen per year is available during the initial period of five years. This corresponds approximately to India's current capacity to produce chemical nitrogen.
3. The capital available for borrowing from outside the village is no more than \$10 per year per person.

Because of the warm climate, fertile soil, and plentiful supply of water, three or more crops a year can be grown in Mangaon (except sugar cane, which takes a full year to mature). Recall that in the Hunan region of China, which is somewhat colder than Mangaon, growing three crops a year is commonplace. Growing three crops a year requires irrigation and fertilizers, and we assume it requires one horsepower per hectare of farm machines. Constraints on capital available from outside the village will limit the initial rate at which projects can be undertaken, assuming that, to begin with, there is no capital available in the village.

We assume that a loan of \$10,000 per year (\$10 per person) can be obtained at a 12 percent interest rate, to be paid back in husked grain at 30¢ per kg and that the first payment would be in the fifth or sixth year. Repayment of the principal and interest in the form of food effectively makes the investment inflation-proof, in an economy where prices are in large measure determined by food prices. It would also make it easier to pay for the labor invested in future development projects with food.

The cost of tubewell irrigation (excluding the cost of the engines

and energy supply) is about \$150 per hectare. (Throughout this illustration we have used the data of the Musahri Plan written by Ranjit Gupta as the basis for estimating capital costs and employment.) Farm machines would cost about \$20 per hectare (\$300 for a 15 horsepower tractor, manual starter). We assume that the engine of the farm machine would also provide the motive power for the irrigation system. If we add \$20 per hectare primarily for drainage works (important in the Gangetic plain) and \$10 per hectare for contingencies and other small but important investments such as food storage, we find that, excluding energy supply, \$10,000 would irrigate and supply the farm machine requirements for about 50 hectares.

A biogas plant to convert dung and plant residues to methane and fertilizer with a capacity of 1,000 million Btu per year would cost about \$10,000. Forty percent of the fuel would be used for cooking to replace the dung so used. We have used the estimates for the biogas plant with gas for cooking (column A, Table 3). No electricity would be generated in the initial period, and the gas would supply fuel for cooking (400 million Btu), for farm machines and irrigation pumps for 50 hectares (500-550 million Btu), and for operating the biogas plant and compressor and pumps (about 50 million Btu).

The biogas plant would also supply 3 tons of fixed nitrogen, 1 ton of phosphorous (P_2O_5), and 1 ton of potassium (K_2O) per year. If 10 kg of chemical nitrogen were available for each of the 300 hectares in Mangaon (that is, about equal to the current use), and if it were used only on the irrigated land, then the supply of nitrogen, organic plus chemical, would be about 120 kg/ha. The timing of the project should be such that the gas plant is completed before the tube-well comes on line. The total cost of this initial phase would be \$21,000, or about two years' supply of capital. This would include \$1,000 for the chemical nitrogen and the \$20,000 in capital assets built during the period. The construction during this phase would employ about 40 people full time (270 days a year) for two years.

Let us assume that on the 50 irrigated hectares three crops of wheat, rice, and green beans are planted during the third year. A rice yield of 2,000 kg/ha (husked) - which is the average for Punjab, and much less than yields in Taiwan and Japan - would increase Mangaon's rice supply by 50 percent from 120 tons to about 180 tons. A wheat yield of 1,500 kg/ha, which is half of that often obtained in Punjab with high-yielding varieties, would increase the wheat supply by 300 percent from 25 tons to 100 tons. When combined with a bean yield of 1,000 kg/ha (dry weight), the total production would just about supply Mangaon's food needs as defined. In addition, the fuel value of the crop residues would be increased from 8×10^9 Btu to about 13×10^9 Btu. Just the extra fuel could supply Mangaon's agricultural energy needs for growing three crops a year on the 300 hec-

tares. This initial phase would create at least 20 permanent jobs in agriculture.

Table 4. Investment and Output in a Multiple Cropping Scheme for Mangaon (in thousands of dollars per year)

| Year ^a | Annual Loan ^b \$ | Total Increase in Annual Output ^c \$ | Locally Generated Annual Savings ^d \$ | Loan Repayment ^e \$ | Investment From Local Funds \$ |
|-------------------|--------------------------------|--|---|-----------------------------------|-----------------------------------|
| 0 | 10 | - | - | - | - |
| 1 | 10 | small | - | - | - |
| 2 | 10 | ? | - | - | ? |
| 3 | 10 | 54 | 13 | - | Food Storage ^f |
| 4 | - | 81 | 20 | 10 | 10 |
| 5 | - | 108 | 27 | 17 | 10 |
| 6 | - | 135 | 34 | 24 | 10 |
| 7 | - | 162 | 40 | 30 | 10 |
| 8 | - | 189 | 47 | 9 | 38 |

^aThe number in the column designated "Year" denotes the number of years from the start of the project. For simplicity it is assumed that the entire capital investment is made at the beginning of the year.

^bThe total investment required per hectare is about \$200. The annual loan is the capital borrowed from sources outside the village, initially assumed to be the only available development capital.

^cIt is assumed that three crops a year are grown - rice, wheat, and beans - and that the yields per hectare are 2000, 1500 and 1000 kg, respectively. The value of the produce is taken as 30¢/kg. Base yield, that is, yield before project implementation, is taken as 850 kg/ha.

^dIt is assumed that 25 percent of all the increases in production over the initial production is retained by the village cooperative for loan repayment and further capital investment.

^eInterest is calculated at 12 percent per year on the unpaid balance.

^fIt is assumed that the savings in year 3 are used to build up emergency food stock.

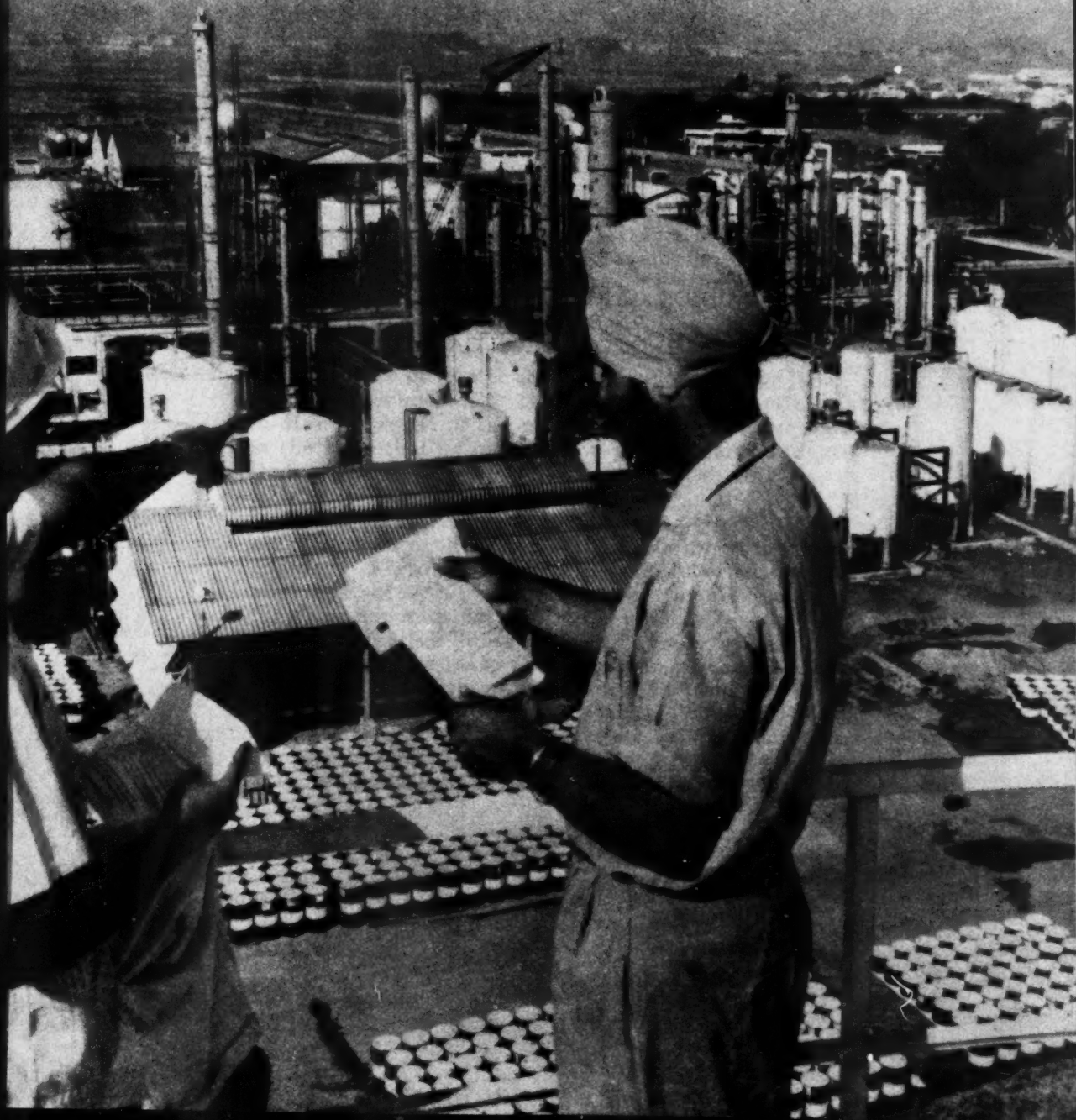
If the next two years' capital were again used in the same fashion, Mangaon could export about 130 tons of grain (wheat and rice) and 50 tons of beans. At 30¢/kg this amounts to \$54,000. The total increase in annual food production at the end of the fifth year would be about 360 tons - around \$108,000. This is about twice the capital invested, including a 12 percent interest rate. From this point on, it should theoretically be possible not only to repay the loan but to finance additional development with locally generated savings. Table 4 shows these financial and production aspects of the scheme in more detail. Note that if 25 percent of the production is retained by the village cooperative to pay back the loan and invest in further development, capital from outside the village is required for only four years.

This illustration is, of course, highly simplified. The pattern of investments would change as development proceeds. The investments made in electricity generation, roads, food storage, domestic water supply, fisheries, animal husbandry, marketing surplus food, and so on, would increase while investments in cooking fuel distribution and irrigation pumps would decrease. As their food needs are fulfilled, people would spend larger and larger portions of their increased income on other essential goods such as better housing or bicycles. This would create additional economic growth and provide for more employment. We have stressed that capital equipment be used as fully as possible so as to augment the investments for small-scale industries or other improvements such as health services.

Accomplishment of this kind is not possible with the present compartmentalized way of doing things, for it requires careful phasing and sustained, cooperative efforts. Achieving such progress is hardly likely to be as fast as we have depicted. But the calculations illustrate that the potential is there for the people of the Gangetic plain to participate fully and fruitfully in economic development, and that this potential can be realized within the rather stringent constraints on capital that exist in India.

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FOREIGN INVESTMENT



A UNION CARBIDE CHEMICAL PLANT
IN BOMBAY, INDIA
(PHOTO: UNION CARBIDE)

Host Countries and Multi-National Corporations

Dale R. Weigel

[Developing countries are pressing hard for a foreign direct investment package that maximizes benefits to the local economy. Tax incentives are disappearing, fade-out regulations are increasing, and joint ventures are becoming more attractive to developing countries.]

It is difficult to imagine a subject that generates more controversy than foreign direct investment by multinational corporations in developing countries. Different observers, sometimes starting with different ideological points of view and often with different sets of facts, have arrived at different conclusions concerning the effect of direct investment by these corporations on the economic development of less developed countries. The purpose of this article is to discuss some of the controversies that have arisen in the hope that some common ground can be identified.

To be classified as multinational, corporations must control production facilities in more than one country. Firms that participate in international business solely by exporting or by licensing technology are not multinational. (Raymond Vernon, limiting the adjective "multinational" to firms that control operations in at least six countries, found 187 U. S. firms that fitted this definition.) Control of a foreign operation may stem from majority ownership of the foreign firm's equity; however, effective control is frequently exercised with less than majority ownership, especially if the equity is widely spread. Con-

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trol may also be maintained by contractual means as with a management contract.

The investments by multinational firms have been an important source of capital for developing countries. During the five years 1968-72 they received \$3.5 billion a year, over 20 percent of their total capital imports, through private direct investment. This is about half as much capital as they received from official development assistance. However, the developing countries as a group have been losing ground to the developed countries as recipients of direct investment. Data for U.S. firms (which accounted for one half of direct investment in developing countries in 1967) show that the proportion of their direct investments in developing areas fell from 42 percent of their total foreign assets in 1957 to 28 percent in 1972.

Monopolistic Advantages

Of course, it is not surprising that foreign investors are attracted most strongly to developed countries. These are the countries where markets are largest and, in many cases, growing more rapidly. So why do foreigners invest at all in the poor countries? In many instances, there are the particular advantages of raw materials and cheap labor to exploit for export production. However, in considering production for the local market, the motives for foreign investment are less clear. Foreign investors must expect higher profits from investing in the developing countries than could be obtained from the available alternatives, but this does not explain why direct investment is larger in some industries than in others, or why some firms invest while others in the same industry do not.

One answer that has come from extensive research in the last ten years is that direct investments in manufacturing industries are made by firms with some kind of monopolistic advantage that is best exploited by maintaining management control of operations in foreign countries. The advantage may be a superior product or production process; lower costs owing to economies of scale or preferential access to capital or raw material; or a product that the foreign company can, through advertising, differentiate from more or less identical local competitors. Some such advantage is a necessary condition of foreign direct investment if the foreign firm is to meet the competition of local firms which are closer to the market and have shorter lines of communication. In fact, it is often the emergence of local competition behind a tariff wall that prompts foreign firms to make direct investments to maintain their export markets.

The available evidence suggests that it is the largest firms located in concentrated industrial sectors that make direct investments: over 70 percent of total U.S. foreign direct investment has been made by

250-300 of the largest firms. The 187 multinational firms identified by Raymond Vernon control four fifths of the total foreign subsidiaries owned by the 500 largest U.S. corporations.

Technological advantages resulting from heavy expenditure on research and development are strongly associated with foreign investment. For example, U.S. direct investment in Brazil during the period 1956-61 was found to be related to possession of a technological advantage as measured by the proportion of scientists and engineers employed. In addition, however, it was also found that direct investment in the technologically advanced industries was more probable when the industry employed relatively large amounts of labor in the production process. On the other hand, in industries without a technological advantage, direct investment was more probable when large amounts of capital were employed. In short, some firms had a technological advantage over Brazilian firms and invested to lower their labor costs; firms without such technological advantages invested only when their access to low-cost capital gave them a competitive edge.

Capital, Technology, and Management

Advocates of direct investment claim it helps economic development in developing countries because foreign investors provide a package of capital, technology, and management and organizational skill. In particular, they contend that foreign investors are able to mobilize both local and foreign capital that otherwise would not have been invested in the country. And, they argue, multinational corporations control within their organizations technology which developing countries cannot obtain from any other source. Foreign investors are also able to provide uniquely qualified management that is capable of providing training for both local labor and management personnel. The advocates of foreign direct investment feel that multinational corporations, with their world-wide production and marketing systems, are able to facilitate exports from developing countries. At the same time, their presence breaks down local monopolies and exposes local producers to competition, so that prices are lowered for consumers.

The critics of direct investment reject many of these claims for uniqueness. They feel that the package of capital, technology, and management provided by the multinational corporation could be obtained from other sources at a lower cost to the developing country. Local capital is absorbed by foreign firms and thus diverted from local firms. The vaunted technology of multinational corporations may be used in the host country, but it is not fully transferred to nationals, since key technical and managerial positions are reserved for expatriates. Finally, it is felt that multinational corporations

break up local monopolies only to impose stronger ones from abroad.

As might be expected, the evidence on these points is mixed. It is clear that foreign investors provide developing countries with a substantial amount of new capital every year, even though some of it is really reinvested earnings. In 1966, subsidiaries of U.S. investors in developing countries obtained 75 percent of their total funds from their parent companies, reinvested earnings and depreciation, and only 25 percent from the local capital market. And there is no question that foreign investors make advanced technology available to developing countries and train local managers and technicians in its use. Firms which spend substantial sums on research and employ large numbers of scientists and engineers are among those most likely to invest. And studies suggest that private foreign investors provide more technical and managerial training in developed countries for citizens of developing countries than do governments through aid programs. Multinational firms also seem to offer more training, and for a broader range of skills, than local firms in the same industry. As a result, less than 10 percent of managerial personnel and about 2 percent of technical personnel employed by manufacturing subsidiaries of U.S. investors in developing countries are expatriates.

There is a question, however, whether the technology transferred by multinational corporations is appropriate for conditions in capital-poor, labor-abundant developing countries. Foreign investors usually do little to adapt their production processes which were developed for use in industrial nations, and which consequently use little labor. The adjustments that are made usually are in peripheral activities like materials handling, or are dictated by smaller markets and short production runs. One reason that foreign firms may not adapt their technology is that they do not have to when their monopoly advantages insulate them from the necessity of minimizing costs. Moreover, distortions in the costs of capital and labor in developing countries reduce the incentive to use more labor. And, in many industries, alternative labor intensive technologies do not exist, or are inferior in terms of productivity and quality of product. Consequently, it is not unusual to find domestically owned firms using the same technology as foreign investors.

Cost to Host Countries

The major criticism of foreign investors is that the cost of this entire package of capital, technology, and management is too high. Foreign investors are accused of using their monopoly advantages and control to exploit the developing countries.

This accusation is difficult to prove. The table below shows that the returns on investments by U.S. firms in developing countries has

not been greater than the returns earned in other developed countries outside of the petroleum industry. High returns on petroleum investments in developing countries largely result from transfer pricing policies which enable the oil companies to take advantage of depletion allowances when computing their U. S. income taxes. The high petroleum profits in developing countries are at the expense of quite low returns on refinery and distribution investments in developed countries.

Profits, interest, royalties and
management fees as percentage of
the book value of U. S. investments

| | 1970 | 1971 | 1972 |
|-----------------------|------|------|------|
| <u>All Industries</u> | | | |
| Developing countries | 20.1 | 21.8 | 22.3 |
| Developed countries | 13.0 | 13.5 | 15.0 |
| <u>Manufacturing</u> | | | |
| Developing countries | 14.7 | 14.1 | 15.8 |
| Developed countries | 14.9 | 15.4 | 17.9 |
| <u>Petroleum</u> | | | |
| Developing countries | 28.6 | 35.0 | 35.3 |
| Developed countries | 5.3 | 6.0 | 7.2 |

Source: Survey of Current Business, Sept. 1973.

Intra-firm sales. Earnings in the table are broadly defined to include profits, interest, royalties, and management fees. Yet it is often charged that reported earnings from these sources understate the true profits earned by multinational corporations on their investments in developing countries. Foreign firms supposedly extract large additional earnings from intra-company sales.

Several instances of such overcharging have been documented in Colombia, where subsidiaries in the pharmaceutical industry paid 155 percent more than the c. i. f. price for intermediate drugs imported from parent firms. Overcharging of 40 percent was also found in the rubber industry, 26 percent in the chemical industry, and 16-60 percent in the electronics industry. (Comparable data on transfer prices paid by subsidiaries in developed countries would be needed, however, to show discrimination among countries.)

While it is possible to dispute these figures, there can be little doubt that multinational corporations sometimes do use intra-firm sales to transfer profits out of developing countries, particularly when the host country limits dividend repatriation. The question is one of degree, i. e., the extent to which such methods are or could be used to exploit host countries. Their scope appears to be relatively limited. For example, total foreign payments, including remitted dividends and interest, of U. S. manufacturing corporations in Latin America were only 8 percent of sales in 1966, of which possibly 5 percent was for imported goods.

We must ask why the parent would want to overcharge its subsidiaries. The principal reasons usually given are to reduce local taxes in countries where tax rates are higher than in other countries where the firm operates, and to circumvent restrictions on dividend repatriations. The possibilities for limiting taxes in this way have been considerably reduced by changes in the treatment of tax havens by tax authorities in developed countries. It may also be noted that manipulation of intra-firm transfer pricing greatly complicates the problems that multinational corporations have in controlling and evaluating the performance of subsidiaries.

Benefits to Host Countries

Each foreign investment has to be evaluated on a case-by-case basis in terms of the alternatives open to the developing country. The net effect of foreign direct investment depends less on the investor's monopoly power than on how efficiently the firm can produce in the host country, and on the host government's economic policies. There is much confusion about the relationship between the net benefits of direct investment to the host country and the monopoly power of the investor. It is usually thought that foreign firms with monopoly power will be able to extract even larger monopoly profits from developing countries by making a direct investment. However, the developing countries are already paying a monopoly profit when they import the product in question. There is no reason why the monopoly profit should increase, after direct investment, unless the host country pays the investor a subsidy that is larger than what is necessary to compensate him for higher costs of production. Regardless of the investor's monopoly power, it is almost always true that investments that do not receive excessive subsidies will benefit the host developing country. A foreign investment that can produce and sell competitively in the world market will produce some additional employment, or higher wages, or additional taxes for the host country. There may be negative external effects, such as the discouragement of local entrepreneurs, but the direct effect should be positive.

The situation is more complicated when it comes to investing in the production for the local market of goods that are not competitive with imports. In that case, the host country will have to pay what amounts to a subsidy, usually in the form of a tariff, to obtain the investment in the first place. The amount of the subsidy will depend on the extent to which diseconomies of scale, higher material costs, or inefficient labor raise production costs. Calculation of costs and benefits becomes still more complicated when the same tariff also benefits high cost domestic firms. It is entirely possible in many cases that the subsidy costs to the economy will exceed the benefits of local production by the foreign firm.

Government Policies

In recognition of this danger, developing countries are changing their policies toward foreign investors. During most of the last 25 years, governments have tried to encourage direct investment by indiscriminately granting tax incentives and tariff protection to foreign firms. In recent years, however, governments are beginning to place greater emphasis on the control of foreign investment. They have come to realize that favorable tax treatment granted by host countries has little effect on the basic decision to invest abroad. At best, tax incentives may induce a foreign firm to locate in one developing country rather than another, so the only effect is to stimulate unnecessary competition between them. Accordingly, many countries are phasing out, or limiting the application of, their tax incentives.

The change in attitudes has also been the result of increased knowledge about the characteristics of foreign investors. In particular, host countries have come to realize that monopoly and oligopoly characterize industries in which there are multinational firms. Consequently, they have attempted to devise policies that would improve their bargaining position vis-à-vis foreign firms. To this end, groups of countries, such as those in the Andean Common Market (Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela), have come together to formulate policy and present a united front rather than compete with each other for foreign investment.

The policies of the Andean Group are more restrictive than many others but are representative of the new directions being taken by a number of developing countries. These include limitations on the amount that can be paid as royalties by local firms (including foreign subsidiaries) for foreign technology. The purpose of this restriction is to eliminate competition by local firms for foreign technology, and thus reduce the price paid. The restriction is also designed to prevent foreign firms from using royalties to extract excess profits from the host country. A more controversial policy of the Andean

Group is the so-called "fade-out." The fade-out regulations require that foreign firms wishing to take advantage of the common market divest themselves of 51 percent of the subsidiary's equity over a 15-year period. Thus, foreign investments must either be, or become, joint ventures. [See Development Digest, January 1974, pp. 81-87, for discussion.]

Joint ventures with foreign firms having monopoly advantages are attractive to developing countries because they enable the countries to participate in the monopoly profits. However, not all foreign firms are willing to participate in joint ventures. Those which are vertically integrated with great interdependence among subsidiaries are particularly unwilling to relinquish control over one part of their international business system. Yet direct investment by such firms may be particularly beneficial to the host country because a substantial proportion of the output may be exported to the parent company. It is for this reason that the Andean Code exempts such export-oriented subsidiaries from the divestment requirement.

In Managing the Multinational Enterprise, Stopford and Wells suggest that joint ventures borrow more locally, pay out a higher proportion of earnings, pay higher prices for foreign technology, and are subject to more limitations on exports than wholly owned subsidiaries. Yet, many developing countries are willing to pay this price for the economic benefits of joint ventures as well as for the political benefits derived from the control of foreign investments. Indeed, political considerations are often as important as economic ones in shaping government policies toward foreign investment. It may be concluded that in the future developing countries will be much more selective with regard to foreign direct investment, and will press harder to obtain greater benefits for the local economy, and that multinational corporations, too, will be more selective in their investment policies.

[Extracted from "Multinational Approaches to Multinational Corporations," Finance and Development, Volume 11, Number 2, September 1974, pp. 27-29, 42. Washington, D. C. : International Monetary Fund and World Bank Group.]

Economic Nationalism and the Copper Industry

Theodore H. Moran

[Beginning with an analysis of foreign investor-host country relations, this article goes on to examine the sequel to the attainment of national control of mines and smelters by four major copper producers. The policies inspired by economic nationalism will need to be moderated if these four countries are not to find themselves suppliers of last resort, suffering disproportionately the impact of instabilities in the world market.]

Relations between Host Country and Foreign Investors

The most familiar frameworks for analyzing foreign investor-host country relations rely on game theory and bargaining models, especially the bilateral monopoly model. The foreign investor has the skills, experience, access to markets, and finance that the country needs to develop its resource base. The country has the ore-bodies, the labor force, and the control over taxation that can be mixed in some proportion to produce an attractive opportunity to the investor. Unless the host government loves foreign investors no matter how they behave, on the one hand, or is anxious to keep foreigners out no matter what the cost, on the other, then the terms under which a foreign investor will be allowed to enter the country and operate there constitute a problem in joint-maximization.

As both the foreign investor and the host govern-

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ment try to increase their returns from the industry, each side has threats to make and benefits to offer. The struggle centers on the relative distribution of revenues that are being generated or that potentially could be generated in the industry. Some kinds of collaborative strategies can increase the size of the pie to be divided and increase the absolute returns to all parties. The host government must weigh the benefits of demanding a larger share of the existing revenue against the prospect of a larger absolute amount (but a smaller share) of revenue if the investor can be induced to expand operations. The foreign investor must weigh his prospects for further profits on the original investment against the chance for larger profits on expanded operation.

The bargaining models or game theory approach are not dynamic enough to show underlying trends in bargaining strength. For a preliminary approach to understanding these trends, one must add considerations about the role of uncertainty. The foreign investor starts from a position of monopoly control over the capacity to create a working operation out of a potential ore-body - a monopoly control that only a few alternative competitors could supply at a broadly similar price. There is always a great deal of uncertainty about quantity and quality of ores, whether the investment can be made into a success, and what the final costs of production and operation will be. The government would like to see its natural resource potential become a source of revenue and employment, but the government cannot itself supply the services needed from the foreign investor and is even less qualified than the investor to evaluate the risk and uncertainty involved. The strength of the bargaining is on the side of the foreign investor, and the terms of the initial concession are going to be heavily weighted in his favor.

Once an investment is made and the operation is a success, the whole atmosphere that surrounds the foreign-host relationship changes. A gamble with large risks has been won, and the host government is unlikely to want to keep paying premiums that reflect those risks for long. In the natural resource field, uncertain investments are frequently turned into bonanzas, and the distribution of benefits from such ventures invariably has the appearance, in retrospect, of the strong (company) cheating the weak (country). If a perception of injustice is not felt after a time by the government that originally negotiated the agreement, it can easily be created by the opponents of that government. And with the investment sunk and successful, the host country is in a position to bring pressure for renegotiation. At the same time that the first mines are successfully opened, uncertainty about the existence of ore-bodies and about the structure of production costs has been reduced for subsequent investors. The government can drive a tougher bargain with later entrants, and this in turn increases the leverage in demanding revision of the original concessions to put them in line with the later agreements.

In short, with the reduction of uncertainty the bargaining strength inevitably shifts from the foreigners toward the host government. In fact, since the end of the Second World War few successful concession agreements in developing countries - in ferrous and non-ferrous metals, petroleum, sulphur, and natural gas - have remained long unaltered. In mining and drilling industries where investment for new production or processing facilities must come in large discrete lumps, the shifts in bargaining power are repeated before and after each new major corporate commitment. Before the investment for new production capacity, a new smelter, or a new refinery, the relative weight of bargaining strength tilts in favor of the foreign investor; after the operation is successful, it begins to tilt back toward the host country.

Producer country learning. A country that has no history of large natural-resource concessions begins, in all likelihood, with a very inexact knowledge of the extent of its mineral or petroleum wealth, and has very little independent capacity to check the feasibility studies or exploration reports presented by foreign investors. In much of the Third World before the Second World War - even in regions not formally colonized - initial investments in resource extraction were undertaken with only the most primitive attempts at bargaining. In Chile, for example, Anaconda and Kennecott were rewarded for their risks in the Atacama Desert or Andes mountains in the early twentieth century with copper concessions that entailed almost no taxes or other obligations. Early international investments in tin, bauxite, zinc, and iron ore were made under much the same conditions. Successful ventures, however, provide an incentive for the host country to develop skills and expertise appropriate to the industry. Beginning with elementary attempts to tighten the bargaining process, the country begins to move up a learning curve that leads from monitoring industry behavior to replicating complicated corporate functions.

The incentive to chip away at the foreigner's monopoly on skills and expertise is magnified as demands for a larger share of the revenues grow and as claims on those revenues multiply. When the oil companies first established themselves in the Middle East or the mining companies in Africa and Latin America, the fiscal needs of the host governments were little more than the personal expenses of their followers and the patronage of their political clientele. But as the Second World War and de-colonization brought social mobilization, urbanization, and import-substituting industrialization to these regions, the idea of playing the game of joint maximization more aggressively with the foreign companies began to become a crucial political issue around the world.

Even those governments most sympathetic to the foreign compa-

nies have not been immune to such pressures, and did not hesitate to respond to them when the balance of power was favorable. In Venezuela, President Pérez Jiménez, who overthrew the more "nationalistic" Rómulo Betancourt in 1950 with the promise of helping the foreign oil companies, found that he needed ever more revenues to finance urban construction and industrial growth. He provoked a crisis in the international industry in 1956 by withdrawing options held by the established producers and auctioning off large concessions to new companies more willing than the old ones to expand output. Successor governments in Venezuela pushed the host-country share of petroleum revenues above 70% in the 1960s with a national commitment to "milk the petroleum" for development.

The value of incremental revenues to sustain growth and/or to dissipate social tensions in countries that are undergoing rapid development and social mobilization is too high, and the political temptation too great, to allow foreign companies undisturbed collection of their monopoly rents. For a country where additional foreign exchange revenues can boost the economic growth rate to 10% per year, the true social return on the increment available for investment is above 20%, while a postponement of that increment for five years reduces its value by half. For a country (with a high or a low economic growth rate) where there is a threat that stagnation may bring social turmoil - or merely electoral displeasure - political elites must make a calculation even more heavily weighted toward developing skills in the present. In short, the development process magnifies the benefits that can be gained by improving the ability to push against foreign companies, and magnifies the costs that will be borne by leaders unable or unwilling to push.

Consequently, as the host-country moves up a learning curve of bargaining skills and operating experience, its relations with foreign investors in the industry do not merely swing back and forth. In time, the country may acquire skills sufficient to operate the industry directly. As the host develops this ability to imitate or duplicate the functions of the foreigner, the cost of nationalism rapidly diminishes.

Nationalization in the Copper Industry

The mid-1960s marked a peak in the flow of equity venture capital to develop or expand copper-mining facilities in "insecure" countries of the underdeveloped world. By the beginning of the 1970s, economic nationalism had gained acceptance. General Velasco had taken over the government in Peru, and, after the nationalization of the International Petroleum Corporation, had imposed stiff new controls over the copper industry. The nationalization in Zaire had been completed. To the south, in Zambia, President Kaunda had taken over 51% of the operations of Roan Selection Trust and the Anglo-American Corpora-

tion - thereby damaging, at the same time, the interests of American Metal Climax and the Rio Tinto Zinc Corporation. Eduardo Frei in Chile had nationalized Anaconda, and Salvador Allende had followed with rapid take-overs of Kennecott and Cerro as well.

All the new nationalistic producers faced the subtle problem of how to make successive governments and their opponents recognize that the cautious manipulation of interdependence (with other producers, including the private corporate producers, as well as with fabricators and consumers) leads to greater strength than the raw exercise of autonomous power. The cautious manipulation of interdependence requires self-restraint and dependability in the use of market power. Further, it requires the ability to make a credible promise that the self-restraint and dependability will continue into the future. For this, the heritage of economic nationalism does not provide a good preparation.

The immediate reaction to the challenge of economic nationalism by the traditional giants in the international copper industry - both those directly affected by nationalizations and those not directly affected - has been simple and predictable: (1) they have shifted their investment plans and their exploration efforts to "secure" areas; (2) they have tried to keep their former market share by "replacing" threatened or lost output; (3) they have been trying to preserve their network of ties to customers, to maintain the selling patterns that they built up with such effort, expense, and patience in the past.

Following nationalization, neither Chile, Peru, Zambia, nor Zaire were willing, in a situation of bilateral oligopoly with customers, to share the burden of fluctuations in supply and demand. They have not given fabricators and consumers a "secure" source of supply. During the course of the Vietnam War, the prices borne by the customers of these four countries rose from about 35¢ per pound to levels frequently about 80¢ for sales in the London market, while the U. S. producers' price stayed from 20¢ to 30¢ per pound lower. Not only did these producing countries try to use full market power during periods of strong demand by leaving the low U. S. producers' price and switching to the higher open market price, but they also sought to cut back production when demand sagged in order to maintain prices at the high level. In 1967 Chile met in Lusaka with representatives of Zambia, Peru, and Zaire to form a producers' organization, the Intergovernmental Council of Cooper Exporting Countries (CIPEC), modeled after the Organization of Petroleum Exporting Countries, to coordinate price and production policy. At least three times since the Lusaka Conference, the CIPEC countries have tried to obtain agreement for cut-backs in production when prices dropped to force them back up. Each time the divergent interests of the member countries have prevented effective harmoniza-

tion of plans for production quotas during periods of slack demand. But the intent of the independent national producers was clear: the new state agencies of these four countries would try to take advantage of short-run inelasticities of supply and demand at each stage of the business cycle to gain the most revenues possible to fund their needs for national welfare and development. The strategy of the CIPEC countries - to confront customers with full market power at every stage of supply and demand - was precisely what the processors and consumers wanted most to avoid.

Such a strategy would work only if consumers had no feasible alternatives. Unfortunately for CIPEC, many major consumers (and their governments) are beginning to calculate the costs of one alternative - namely, integrating backward to their own "secure" supplies - and finding that the results may be worth the effort. The initial CIPEC strategy of capitalizing on the position of strength under conditions of extreme copper shortage (1966-1969) provided the stimulus for industrial fabricators and consumers, and their governments, to take unprecedented steps to develop new sources of copper. Such steps have now been continued even through periods of weak demand.

For the first time, the West German government has been following the pattern of the Japanese in financing new mining operations on the basis of repayment in ore. The Kreditanstalt für Wiederaufbau, the German state reconstruction bank, has lent substantial amounts of development capital to American companies in Southeast Asia and Oceania and to British and American companies in some parts of Africa (not Zambia) in return for long-term contracts for a share of the output. West German, Swedish, Belgian, and French capital have flowed to Canada to finance or take equity participation in new mines. The Pechiney-Tréfinmétaux group in France, formerly interested primarily in aluminum and nickel, are becoming copper producers in Australia. The Japanese Ministry of International Trade and Investment, coordinating the efforts of governmental agencies, private trading groups, banks, and mining and fabricating companies, has continued that country's voracious search for copper in Canada, the South Pacific, Southeast Asia, and some parts of Africa.

In sum, the consumers and fabricators of copper in the major industrial countries have been integrating backwards to develop their own secure sources. Their governments have been encouraging them to move upstream and have also been supporting the formation of other mining companies that can be depended upon to be regular suppliers of copper. CIPEC use of untempered "monopoly power" in the past, inspired by Chile, has stimulated this movement to weaken the producers' oligopoly.

Dangers of Market Dualism. There is a danger posed by the

pricing and marketing strategy of the CIPEC producers that is more immediate than the long-term effects in reduction of their world market shares. It consists in the potential development of a dual market system in which the CIPEC countries gradually become suppliers of last resort, outside the main network of semi-integrated ties between corporate producers and consumers, onto whom will be shifted the major costs of uncertainty about supply and demand for the entire industry. The reason for the evolution of a new dual structure lies in the persistence of a preference among consumers for ties of informal integration to the mining state - ties that the new independent state producers have been unwilling or unable to maintain.

The impetus for vertical integration can come from two directions - from producers who want "secure" outlets, and from processors or consumers who want "secure" sources of supply. "Security" is a judgment about the relative risk that the producer, processor, or consumer runs of meeting sudden market power being wielded against him - especially market power wielded unevenly against himself and not against his competitors - at some stage that he does not control. If there is a high risk, he measures the cost of the threat to his operations against the costs of neutralizing or minimizing the threat. Calculations of this sort are impressionistic and subjective. But they are the basis for strategy. The formal and informal bonds of vertical integration in the copper industry were built up because inelasticities of supply and demand in the short run had tended to shift market power abruptly back and forth from producer to fabricator or consumer. In a situation of bilateral oligopoly such as this, where there is a large exposure to risk, both sides may be willing to pay a premium to reduce that exposure.

From the point of view of the consumer in the international copper industry, the risk of large blocs of copper being removed unpredictably from the market, creating sudden and severe shortage, remains high. Transportation difficulties for Zambian copper moving through Rhodesia or Tanzania create periodic uncertainty about delivery, as do port strikes in the United States or Europe. A cave-in at Mufulira in Africa in 1970 took 150,000 tons, or 20% of Zambian production, from the market in one blow; a mudslide in West Irian or Bougainville in the monsoon season of the South Pacific could do the same thing. New production simply cannot be brought on-line in the short run in time to prevent a sharp rise in price with an absolute shortfall for many users, and a temporary switch to aluminum, plastics, or specialized steels is not easily accomplished at the margin by fabricators, nor, once accomplished, easily reversible.

These risks have been compounded by labor difficulties. Twice in the 1960s there were prolonged strikes among copper workers in

the United States, cutting off almost all American production. As the CIPEC countries move toward complete national control of production, their labor problems appear to be becoming more serious, too. In the past, despite frequent short strikes, the aggregate production record of Chile, Zambia, Peru, and Zaire has been quite good. Allende's efforts to keep Chilean miners' salaries within the limits of his stabilization program, however, provoked a 75-day strike in 1973 and the stoppage of all exports for almost three months. It may prove to be more difficult than it was with private companies for governments with direct control to minimize strikes and keep production costs competitive while insuring a steady flow of output. Already the costs of production in CIPEC countries have risen sharply, due in part to pressures for increasing employment in national industries.

An additional uncertainty for consumers has been introduced by the debates in various CIPEC countries, especially Chile, about selling copper to communist countries. The major problem in this for consumers is uncertainty in the face of inelastic supply - not ideology. If some or all of the CIPEC countries were to establish regular trading patterns that allocated, for example, 10% of their annual output under long term contracts to Eastern Europe and 5% to China, the uncertainty would be removed. But there is no predictability about supply when trade policy changes, or threatens to change, with each new President or each new Congress or each new state administrator.

To hedge against the threat of undependable supply, against the threat of market power being wielded unevenly against them, the major copper consumers have been continuing to show a strong preference for establishing ties of formal or informal vertical integration. The private corporate producers are responding sympathetically to that preference, as they have for decades. The new national producers are not. The danger for the new independent national producers is that they may end up paying the insurance premium for the entire international industry. The major private corporations and their governments may well not have to bear most of the costs of maintaining excess capacity, or maintaining inventories, or providing consumers with insurance against meeting unavoidable monopoly power at the production stage. The national producers may find that their policies will lead them to be forced to accept those costs for the entire industry.

It is quite possible that planners in the governments of Chile, Peru, Zambia, and Zaire have too easily accepted the conventional marxist argument that large industrial societies need the raw materials of the Third World and will collapse without them. This has led the nationalists to assume that by controlling the sources of raw

materials, they would be in a position of consummate strength. But there is nothing in history or logic to suggest that corporate boards of directors will simply sit and let the price and terms of supply be dictated to them by outsiders if they have other options available to them. Without the necessity of alleging either malice or conspiracy, it is now evident that fabricators and consumers and their governments are willing to act to the extent of their powers to protect themselves.

By adopting the strategy of using the full extent of their market power at every point of the business cycle, the independent national producers offer no incentive for a fabricator or consumer to maintain ties with them rather than seek alternative sources or integrate backwards to develop supplies of its own. They make themselves into suppliers of last resort. Their share of world production is still in the early 1970s sufficiently large (35%-40%) that there cannot and will not be a massive defection from them as suppliers. But there has been a trend for major consumers to try to cover the bulk of their needs from the semi-integrated system of corporate producers as fast as the companies can expand output, while treating the CIPEC production more and more like a spill-over market. If consumers cover the bulk of their needs from sources in the integrated industry during both the expansion and the contraction phases of the business cycle, a 10% variation in aggregate demand that is passed onto the CIPEC market would require a 30% change in production (or inventories) for them, and a much greater change in net revenues,

Those proud and independent nationalists will find their small (and probably competitive) market getting only the notoriously unstable edge of demand. Industrial consumers will provide for the majority of their orders through scrupulously regular positions on the sales books of the major private producers, reserving for the independents only the variable margin of their needs. If the CIPEC countries make themselves into a spill-over market as suppliers of last resort through the full use of their individual or collective market power, they will operate at full capacity only in the boom phase of the industrial business cycle, and hold inventories for the entire industry (or clear their production in price competition with each other at discounts that may fall below average cost) the rest of the time.

Alternatives. There seem to be two clear courses of possible evolution for the relations between the new independent national producers and the larger world industry: First, there is the course that has been followed thus far, in which the independents continue systematically to break ties, pursuing something called independencia or autonomia, and scorning close dependable relations with final customers in the large industrial countries. Second, there is an alter-

native course, in which the independents seek reintegration with the world industry, reestablishing informal vertical ties of their own and conducting themselves like the other producers, recognizing and emphasizing and taking advantage of interdependence. It requires a moderation in coordinating production that is not aimed at exploiting inelasticity of demand to the fullest extent possible in both boom and slack markets. It requires, in effect, joining the oligopoly and playing according to its rules.

There is no reason why, with proper stress on performance and reliability, the economic nationalists cannot occupy a position within the international industry as strong or stronger than any private multinational copper corporation. Unless the CIPEC countries deliberately fashion a price and marketing strategy to make themselves into suppliers of last resort, the large corporate consumers may come one day to consider them suppliers of first resort - if their domestic pressures for foreign exchange could be translated into policies that would limit any long interruptions in production. In the United States, Western Electric and General Electric, General Motors and Westinghouse will be happy to import a regular portion of their needs from Chile if the country will insure them of dependable supplies in the event of a domestic strike. In Europe and Japan, British Insulated Callender's Cables, Norddeutsche Affinerie, Volkswagen, or Mitsubishi will continue to be content to get most of their copper from Chile, Zambia, Peru, and Zaire, even with the increasing penetration of their economies by vertically integrated foreigners, if they are not put at a competitive disadvantage to their rivals from the United States. What the CIPEC producers must devise is a pricing and marketing strategy calculated to moderate the pressure felt by fabricators or consumers to integrate backwards themselves, and to eliminate the pressure felt by the fabricators or consumers to seek closer and more durable ties with alternative producers. In short, the new national producers must carefully learn to treat the consumers in the industrial countries exactly the way the multinational corporations do.

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International Sub-Contracting

Michael Sharpston

[Over the last ten years there has been a rapidly increasing tendency for firms in developed countries to contract-out to producers in developing countries the manufacture of certain products or components, and the performance of certain processes. Final sales are in developed country markets. This paper assesses the current scope of that phenomenon, analyzes the reasons for its growth, and considers its economic and political effects.]

There is no agreed definition for international sub-contracting. The definition used here is: all export sales of articles which are ordered in advance, and where the giver of the order arranges the marketing. International sub-contracting can be divided into the sub-contracting of processes, sub-contracting components, or sub-contracting whole products. The types of firm giving the sub-contract may be producer firms, i. e., overseas organizations which themselves produce similar products (e. g. Mortorola, Texas Instruments), or retailing firms (e. g. Sears Roebuck). A wide range of possibilities exist with regard to the business relationship between the principal and the sub-contractor. The sub-contract itself may be long-term, short-term, or for a single batch. The principal may own a minority, majority, or the whole of the equity of the sub-contractor. He may provide loan capital; he may also provide physical equipment for the sub-contractor. Furthermore, the principal may provide technical assistance to the sub-contractor. There are many possible combinations of these various forms of business relationship, so that in

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practice a complex range of business relationships between principal and sub-contractor exists all the way from the sub-contractor being a wholly owned subsidiary of the principal to single-batch sales at "arms' length." All forms of international sub-contracting have one important characteristic in common: sub-contracting avoids the problems of marketing.

A typical example of the type of international sub-contracting which has arisen in recent years is that for semi-conductors: in 1973 the United States had imports from developing countries worth \$190.7 million of semi-conductors with some American components. The wafer which is the heart of the semi-conductor is exceptionally light and typically smaller than a fingernail: it is fabricated in the United States. The wafer and other components are then flown to say, Taiwan, where labor costs for assembly are about one-tenth of American ones. Under magnification, the gold threads are soldered to the terminals, and the finished semi-conductor is flown back to the United States. About 40 percent of the gross value of the returned U. S. import is the value of the U. S. components, so that the value added in the developing countries would be \$113.6 million of the \$190.7 million. In a recent study, not a single U. S. semi-conductor firm answering the questionnaire did not have off-shore assembly facilities, and European firms have been forced to follow suit or cease production.

The Current Scope of International Sub-contracting

One source of quantitative data on international sub-contracting is Economic Factors Affecting the Use of the Items 807.00 and 806.30 of the Tariff Schedules of the United States (U. S. Tariff Commission, September 1970). Customs items 807.00 and 806.30 permit an importer, under certain conditions, to pay duty for the product imported only on the value added abroad; no duty is paid on the value of the U. S. parts or materials incorporated. Not all products which involve international sub-contracting will necessarily qualify under these customs items; and the Tariff Commission report only deals with U. S. imports. Nevertheless, it is easily the most important source so far available.

U. S. Tariff Commission data give some idea of the rapid growth of international sub-contracting (Table 1). The share of developing countries in U. S. imports under these two tariff items rose from 6.4 percent in 1966 to 35.9 percent in 1973. U. S. sub-contracting in developing countries in 1973 was twenty-five times the 1966 level, an annual compound growth rate of about 60 percent for seven years. Information on the amount of sub-contracting arranged by firms from other developed countries is rather fragmentary. The increase in Japan's use of international sub-contracting in the late 1960s was also very rapid as indicated indirectly by some investment data.

Table 1. U. S. Imports under Tariff Items 806.30 and 807.00, 1966-73 (Value in millions of dollars)

| | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 |
|--|------|------|------|------|------|------|------|------|
| Total Imports (as specified) | 953 | 1035 | 1554 | 1852 | 2213 | 2768 | 3709 | 4247 |
| Imports from developing coun- tries | 61 | 99 | 222 | 395 | 542 | 653 | 1032 | 1323 |
| Dutiable value of imports from de- veloping countries* | 31 | 43 | 98 | 177 | 246 | 314 | 531 | 827 |

* value added overseas plus freight cost.

Source: U. S. Tariff Commission, published and unpublished data.

Reasons for the Growth of International Sub-contracting

Demand for international sub-contracting is a derived demand: it depends on the pattern of demand for final products in the developed world, their method of manufacture, and cost differentials. Among final products, in recent years new labor-intensive products in the electronic field have been added to the old labor-intensive manufactures such as clothing and shoes. There has been buoyant demand for products which require labor-intensive manufacture. Within this structure of final demand, demand for international sub-contracting has principally been in response to the differential between labor costs in the developed and the developing countries; this differential has been rising and is likely to continue to do so. Even if U. S. wage rates go up by 5 percent, and Korean rates by 20 percent, the absolute differential between the rates becomes larger. Furthermore, for certain tasks, it has increasingly been found possible to obtain labor productivity in the developing countries close to, or exceeding, U. S. levels. At the same time the logistics of an overseas sub-contracting operation have become easier. There have been developments such as increased availability of air freight facilities, and containerization; and telecommunications have greatly improved between many developing countries and the major industrial nations. Demand for international sub-contracting has also, to some extent, been encouraged by governmental regulations in developed countries. Several developed countries have tariff regulations which permit low effective tariffs to be levied on the further processing abroad of semi-manufactures produced in the developed country.

Despite the importance of the factors mentioned, it would probably be a mistake to see the enormous rise in international sub-contracting as having been solely due to an objectively ascertainable change in comparative costs. Attitudes also have changed; there has been an increasing willingness among firms now called 'multinationals' to think in terms of world-wide production and marketing possibilities, rather than treating overseas operations as separate from their operations in the home country. The move to international sub-contracting has been in the nature of an innovation in production systems: the pioneers in a particular industry have typically soon been copied by a wave of competitors, who often establish sub-contracting facilities in the same overseas countries as the pioneer firms. Similarly, American use of international sub-contracting has forced European and Japanese firms to follow suit.

On the supply side, developing countries have shown an increasing readiness to make themselves available for international sub-contracting operations. By the late fifties and early sixties many countries had found import substitution an unsatisfactory method of industrialization, particularly for small countries where there were serious difficulties in obtaining adequate economies of scale. It is no coincidence that international sub-contracting has been most in evidence in countries such as Hong Kong, Singapore, Taiwan, and Korea, where the small size of the domestic market made open economic policies particularly desirable. At the same time, there was a growing emphasis among development economists on export- rather than import-substitution, and indeed this has now become the new orthodoxy, affecting government policy in quite a few developing countries. An increasing minority began to open up their economies, making importation and exportation easier, and often also providing certain direct or indirect subsidies to export industries. Within this field of exportation, international sub-contracting permitted access to developed country markets without the risks and problems connected with foreign marketing. In many cases - for example, the supply of certain components of a product or the performing of certain processes - direct exportation was not in fact a feasible alternative to international sub-contracting. Through international sub-contracting, a developing country might obtain technical assistance, and often capital, without which the industrial operations involved might not have been possible. Thus from the mid-sixties onwards there was an increasingly favorable environment, on both the demand and the supply side, to the rapid growth of international sub-contracting.

Labor costs. It is possible to find cases of international sub-contracting which depend on the low cost of production inputs other than labor; for example, alumina is imported into Ghana for processing into aluminium and subsequent re-export, solely to take advantage of a very low rate for electric power. Nevertheless, labor-intensity of

a product or process is the most typical reason for which international sub-contracting in developing countries occurs. However, labor cannot be regarded as a single, homogeneous, factor of production. Unskilled labor is indeed plentiful; but skilled labor often is not, and in many countries supervisory and management personnel are extremely scarce. The availability of different types of labor varies widely across the developing world. In Morocco, for example, salary scales for Moroccan or locally recruited European supervisory personnel are as high as in Europe; if it is necessary to import expatriate senior staff, costs in Morocco are 25-30 percent above that cost of equivalent grades in Europe. In many countries less developed than Morocco, costs of supervisory personnel could be double those of Europe. In some Far Eastern countries, however, certain grades of skilled labor and supervisory personnel are now available at low wage rates relative to the rest of the world.

International sub-contracting operations in developing countries tend to be intensive in their use of unskilled or semi-skilled labor, but not intensive in their use of skilled labor or professional manpower. Manual dexterity of a high order may be required, but the typical international sub-contracting job is one which can be learned in roughly six weeks, perhaps from the base of traditional skills. Thus in Morocco, in six weeks girls (who may not be literate) are taught the assembly under magnification of memory planes for computers - this is virtually darning with copper wire, and sewing is a traditional Moroccan skill. Of the total 807.00 imports into the United States from developing countries in 1969, for example, the major items were:

| | % | | % | | % |
|------------------|------|--------------|------|---------------------|------|
| Textile products | 8.6 | TV apparatus | 8.3 | Electronic memories | 10.2 |
| Office machines | 8.3 | Semi-con- | | Toys, dolls | 5.9 |
| TV receivers | 10.8 | ductors | 23.6 | | |

For all these products the sub-contracting operation would typically have consisted principally of assembly work; and these items alone constituted over three-quarters of the gross value of all 807.00 imports.

Because most developing countries lack an industrial tradition, it will often be necessary to have a higher ratio of supervisory personnel to manual workers than would be required in a developed country. But physical output per manual worker may often be similar to that in developed countries, and in some cases higher. The 1970 study of the U. S. Tariff Commission found the greatest difference between labor productivity in the United States and overseas in the case of garment-making in Mexico where it was about 60 percent of the U. S. level. For electronic assembly, foreign labor productivity was about 92 percent of the U. S. level, and for other items the productivity differential was still smaller, even in some cases negative.

More recent research indicates worker productivity in the Mexican Border Industrialization Program at 80-140 percent of U. S. levels. High labor productivity is also found in Korea. In Morocco in 1972, management in many plants estimated labor productivity under similar conditions to be 85-90 percent of the European level. There is some evidence that a comparison of labor productivity in developed and developing countries is most likely to be fairly favorable to the developing country for machine-paced jobs.

It is also likely that labor productivity in some international sub-contracting operations is increasing rapidly over time as the labor force gains industrial experience. Labor turnover and absenteeism may also be lower than in a developed country. One must consider that jobs suitable for international sub-contracting are often low-grade, undesirable jobs in developed countries; in developing countries, however, the same jobs are often highly sought after. In many such countries high urban unemployment makes any regular employment very desirable, and factory conditions will often be pleasant compared with working conditions in other jobs. Whereas in the developed country, the job will typically be very ill-paid relative to other jobs, in the developing country the opposite is usually the case.

Even where labor productivity in a developing country is substantially below normal levels in the developed world, differences in wage rates are so great that it may still pay a multinational corporation to do international sub-contracting. Comparisons of annual average hourly earnings in manufacturing in 1970, for example, show: averages of \$3.00 or more in the U. S. and Canada or \$1.50-2.50 in northern Europe, as against averages of \$0.30-0.50 in Latin America and still less in much of Asia - e. g. \$0.15 in Sri Lanka. The differentials in particular labor-intensive jobs may be even greater than among national averages. Thus in 1967, U. S. wages in garment-making were about twenty times those in Korea. In 1972, an hour's workshop labor by an electrical worker would be costed at U. S. \$0.80 per hour in Morocco, as against \$3.00 to \$3.50 per hour in France (all overhead costs included). Typically, labor productivity differentials in favor of the developed country - where they exist - have little effect in eliminating the vast differential in wages. Thus according to U. S. Tariff Commission data, the net Far East labor cost for electronic assembly would be only 8 percent that in the United States.

At first sight, it may seem difficult to reconcile such wage data with the fact that, in very many cases, technical costs of production for the domestic market are far higher in a developing than in a developed country - not only non-labor costs but labor costs as well. In production for the domestic market of a developing country, production runs are often far shorter than in a developed country, with a consequent need for the frequent time-consuming and expensive

re-tooling between runs. Often management is inferior; and for small-scale operations high-grade management would often be uneconomic as constituting too high an overhead. With international sub-contracting, however, production is for developed country markets, so the production runs and size of plant can be those found in developed countries. Multinational corporations can obtain management of similar quality. Machinery available can also be identical. Alternatively a multinational corporation moving production to a developing country may often be able to achieve an even greater fall in total costs of production by some substitution of labor for capital. For example, low labor costs may make it cheaper to use hand labor rather than machinery for certain packaging or assembly operations, or permit profitable processing of scrap where this was not an economically viable operation in the developed country.

Suitability for international sub-contracting requires that a particular product or process must be labor-intensive in developed countries. For example, the overall production of semi-conductors is both skill- and capital-intensive, but one particular phase in production - assembly - is very intensive in its use of easily trained labor, and accordingly, semi-conductors are an extremely common object of international sub-contracting. The labor-intensive production processes in manufacturing are those which for one reason or another have resisted the whole trend of technology in the developed countries, which has been to mechanize production wherever possible. Very often, these processes are assembly operations; or certain kinds of finishing operation (e. g. cleaning, buffing and polishing), particularly of complex shapes. Another case is sand-casting: this is typically labor-intensive work of a hot, messy kind which workers in rich countries do not like (and can afford not to like).

Perhaps the most important single operation which resists mechanization is sewing: industrial sewing of clothing really resembles, quite closely, sewing with a domestic sewing machine. This makes garment-making an ideal operation for international sub-contracting, from the technical point of view. For the cutting, one can use laser beams, and computer-designed patterns to reduce waste; but 80 percent of the labor cost of clothing manufacture is in the sewing stage, and this is extraordinarily difficult to mechanize. For a long time garment-making is likely to remain labor-intensive, and a factory with quite advanced machinery still only represents a fixed investment of around \$2,000 per work place, of which the building itself is the largest part. Fixed investment per work place in a modern textile plant can be seven or eight times as large. And there are equivalents to sewing in the electronics field: for example, the manufacture of electronic memories which would be most difficult to mechanize. There is also an equivalent of a kind to sewing in metal-working: soldering and welding.

One situation in which most production processes tend to be labor-intensive is the production of any type of article at all in small production runs or non-standard sizes. Short production runs do not permit the amortization of highly specialized and automated machinery. In an enormous variety of industrial fields, practical discussion of international sub-contracting possibilities boils down to: 'Where are the short production runs?' It applies for electric motors, electronics, vehicle parts, railway wagons, pharmaceuticals. For a short production run any country will have to use simple technology, and production will, therefore, be labor-intensive. Indeed, firms in developed countries may not want small volume work; it disrupts large factories. In this way, a Moroccan firm recently won an international sub-contract to make refrigerators. Of course, small production runs by developed country standards may be still very large for a developing country, and the Morocco refrigerator firm in question will now triple its total annual production. One field where quite short (hence labor-intensive) production runs still predominate even in developed countries is machine tools; it is therefore a possibility for some of the more advanced low-wage countries. Spain, for example, is building up a substantial export business in simple low-grade machine tools. Although short production runs can be a very good way into international sub-contracting, it would be wrong to suggest they are the only long-term international sub-contracting possibilities. In Taiwan and Singapore, electronics firms are now setting up plants for long production run manufacture of radios and television sets for the world market.

In broad terms, automated production has the advantage of repeatability and precision, while labor-intensive production has the advantage of flexibility. Thus the aircraft industry commonly uses automated techniques, for reasons of precision; conversely an industry using a natural material which is expensive and non-uniform (e. g. leather) will keep to labor-intensive techniques, for reasons of flexibility - a man can adjust the cut he makes to the individual piece of material. The superior flexibility of labor-intensive techniques is also an advantage in a situation of very rapid technological change. This can for example be an important consideration in electronics.

Labor-intensive international sub-contracting possibilities are not confined to non-agricultural products. Preparing food for processing often involves a good deal of hand labor: taking off shells or husks, cleaning, and so on. As a result, the frozen strawberry industry is tending to move out of the southern United States into Mexico. International sub-contracting is also possible for services: aircraft-servicing and ship-repair (e. g. in Singapore), card-punching of data for computers (e. g. in Jamaica), printing (e. g. in Hong Kong).

Freight and "distance" costs. Freight costs and other costs associated with distance are another major factor affecting the feasibility of an international sub-contracting operation, particularly for the sub-contracting of processes. In this latter case, a production system can only in effect be split up if the costs of double haulage - to the developing country and back to the developed country - are sufficiently small. (Separation of a process may also involve special extra costs, such as reheating, wrapping, protective greasing of metal, etc.). Freight costs vary with many factors, but the critical factors are typically weight and bulk. Because parts have a higher value-to-weight ratio, international sub-contracting is usually easier in electronics than for electrical goods, and easier for electrical goods than for most mechanical engineering products.

One effect of freight costs is of particular interest. High freight costs act in favor of import-substitution, but against exporting. This may create openings for international sub-contracting by some developing countries for markets in other neighboring developing countries. Here high freight costs can make it easier for certain developing countries to engage in international sub-contracting. The more industrialized developing countries may be able to manufacture certain products or perform certain services which neighboring less advanced countries need; and their proximity and their low wage-rates relative to the developed world may make them competitive. For example, Morocco repairs electric equipment for Algeria, and sells radiators for special purpose vehicles to Senegal. For this type of international sub-contracting, the transport costs involved in a bulk-creating process (e. g. assembly) could be a favorable factor, since they create natural protection from competition by developed countries further away. International sub-contracting for other developing countries could also provide a training ground in which to gain exporting experience and improve quality standards.

In addition to freight costs, important costs are incurred in international sub-contracting simply because of the distances involved. The logistics of the operation are far more complex than for production within the plant of the principal. The 'pipeline' is longer, with more points at which it can be interrupted: inventory might need to be one or two months' production, rather than only a few days. There are also the costs and problems of communication, and the executive travel time involved. With greater distance, modification of product specifications as a result of afterthoughts or in the light of experience becomes much more cumbersome, a particularly important consideration with 'one-off' operations or short production runs. The combined impact of freight and distance costs is evident from the success of Mexico in international sub-contracting for the U. S. market despite its comparatively high wage-rates.

A point of the utmost practical importance is the way in which developing country governments can artificially increase effective "distance." Casablanca, the main industrial center in Morocco, is three hours by air from Paris, and three days by sea from Marseilles. However, importation of an article for processing and subsequent re-export will involve importation en admission temporaire. Because of the complex bureaucratic proceedings to be followed, the "administrative distance" from Europe to Morocco for imports becomes two to three months. Similarly, the Moroccans are anxious about flight of capital via the under-invoicing of exports, and impose various checks: this creates further delays and expense for a potential sub-contractor in Morocco, and may make him feel he is under suspicion. As against this, the countries well known for sub-contracting have relatively less severe barriers to the free movement of goods. Indeed, Mexico has an entire border strip with the United States as a free trade zone. Hong Kong and Singapore are essentially free ports.

The influence of governments. The governments of developing countries, in many cases, impose such severe bureaucratic obstacles to international sub-contracting as to render it almost impossible. Usually, this is the actual effect, and not the aim of government policy; but it is probably no coincidence that so many developing countries have severe institutional barriers to international sub-contracting, and indeed more generally to exporting. Industry tends to be inward-looking, with a built-in tendency, often fostered by an over-valued exchange rate, to believe that it cannot be competitive on world markets. Quality standards will be at the minimum level required in a heavily protected market of poor consumers. Importing is not only subject to high tariffs or to quotas, but is also made very cumbersome by bureaucratic barriers. Fears of capital flight can create almost equally severe barriers to exporting. More generally, there is an atmosphere of dirigisme. Most developing countries are geared to planning via controls; and market forces, particularly international market forces, are viewed with deep suspicion. I. M. D. Little's aphorism, "Planners do not like exports," is barely an overstatement: the planning ideology does tend to foster autarky. And bureaucratic barriers to the setting up of the actual sub-contracting plant can also be a very important disincentive to sub-contracting operations.

While many governments of developing countries still hinder international sub-contracting with severe bureaucratic obstacles, a few are now turning to export- rather than import-substitution, and providing substantial incentives to trade and exportation. A prominent example is Korea. Firms engaging in international sub-contracting get subsidized credit for their working capital. Allowances for materials wastage in processing are very generous and allow a hidden profit from sales on the home market. Direct or indirect

export subsidies (including bonus exchange rates) can certainly increase the attractiveness of a country as a base for international sub-contracting. Tax holidays may be applied, although there is some evidence that they have relatively little effect on investment.

A crucial factor affecting international sub-contracting is the apparent political stability of the government of the sub-contracting country - not for the sake of ideology, but on a practical business level. The main concern of a principal is with security of supply, also the security of any possible investment. If there is believed to be a serious danger of expropriation of foreign-owned factories, firms will avoid any operation with a pay-back period of more than two or three years. Alternatively, principals will adopt a form of business relation with their sub-contractors which limits their own financial risks. In addition, because an interruption to supplies would affect the principal's own factories, it is common for firms to spread their sub-contracting business over a variety of countries, and to have "back-up" or "reserve" production capacity at home. Other dangers to security of supply include the possibility of strikes at the sub-contractor plant, or at the docks; and unpredictable and erratic customs clearance.

Government policies in the developed countries, particularly on tariff and non-tariff barriers to imports, can also affect the scope and direction of international sub-contracting. Items 807.00 and 806.30 of the U. S. Tariff Schedule have been mentioned; the United Kingdom and Japan have similar provisions, but subject to far tighter restrictions on their use. West Germany makes importers pay the effective tariff on the value added abroad. For products where developed country protection is substantial - notably many processed agricultural products, textiles, and clothing - preferential access to a developed country market can weigh heavily in the choice of sub-contracting country. Thus Far Eastern textiles are largely shut out of the E. E. C. by quota, but E. E. C.'s Associated States are exempt from both quotas and duty, so they have access to a heavily protected export market.

Benefits and Dangers for the Developing Country

International sub-contracting vs. direct exports. For the developing countries, an alternative to international sub-contracting is direct exportation. The essential difference is that sub-contracting avoids the problems of marketing: outlets, brand names, publicity, market research, design. In many cases it is possible for exporters to buy most of these marketing services separately. For many products, however, the scale of investment required in overseas marketing facilities may be far beyond the capabilities of most developing countries, particularly where successful product differentiation imposes a high initial sales campaign cost on potential new entrants

to a market. This would be true for most consumer durables, where effective marketing implies the establishment of a network of after-sales servicing facilities (with the concomitant investment in stocks and warehousing for spare parts). Also, organizations such as Sears Roebuck in the United States or Boots in Britain benefit from large economies of scale in marketing which are related to the total volume of their sales rather than the sales volume for any particular product - economies that it would be very hard for a developing country exporter to duplicate. Closeness to the market is a most important advantage of local firms, either for consumer fashion goods or for industrial products which require technical selling. To overcome its problem of distance from the market, a foreign firm operating on its own may be forced to set up an expensive local office with high-level staff.

International sub-contracting offers a solution to such difficulties. In the case of international sub-contracting of components and processes, direct exportation would often be quite impossible for a developing country. Thus one clear benefit of international sub-contracting is that it permits a developing country access to certain markets which would otherwise not be available. Even where direct exportation is a feasible alternative, international sub-contracting may well enable the developing country to achieve a far faster growth in exports. One reason for this is that it enables production to be guided by strict quality controls based on specific consumer requirements.

Dealing with multinational corporations. An issue much discussed is whether it would be better for developing countries if they could buy separately the items in the multinational corporation package - capital, management, technical know-how, marketing. In this context, international sub-contracting can certainly take a wide variety of forms: one-off orders (e.g. for clothing), long-term contracts, and then varying degrees of technical assistance and capital participation right up to the wholly owned sub-contracting subsidiary of a large foreign firm. Firms may have a stronger or weaker preference for wholly owned subsidiaries: American and British firms seem to have a strong preference for wholly owned subsidiaries while this is much less the case with continental European, Japanese, or Australian firms. Prima facie, there would seem to be grounds for believing that there is more encouragement to local entrepreneurship if the sub-contracting relationship is of the contract rather than the subsidiary form. As against this, in one of the closer forms of business relationship the principal is more likely to provide technical assistance. Also, subsidiaries of multinational corporations can bring to a developing country resources of management skills and of risk capital which would not otherwise be available.

It is often argued that it is inherently risky for a country to be dependent on the subsidiaries of multinational corporations for pro-

duction and exports: that corporate executives may suddenly decide to reshape production and export systems. However, dependence - with all the risk that it inevitably entails - may be as critical a problem with "arms length" contracts as with wholly owned subsidiaries of multinational corporations. Just as a multinational corporation can switch its sub-contracting business from a Taiwan to a Korean subsidiary, so also it can switch its "arms length" contracts - indeed, with contracts the switch is easier, since the multinational corporation is not directly responsible for the people it throws out of work by the shift. In a volatile political situation, the principal may well prefer a contract relationship - less financial risk and commitment for the principal, but by the same token less assurance of future work for the sub-contracting country. Furthermore, one may well wonder how independent a sub-contractor with one or two dominant clients really is; in practice, the principal under such circumstances may be able effectively to control the sub-contracting firm, whether or not it has any share of the equity capital. With so many different situations possible and so many considerations involved, there is probably no form of business relationship which is always better, or always worse, than any other from the point of view of either the developing country or the foreign firm.

One industry, vehicles, illustrates particularly well the problems of a developing country in fostering industrialization, engaging in international sub-contracting, and dealing with the multinationals. Because of the economies of scale which arise, an attempt to increase local content per vehicle by import-substitution normally leads to a steep rise in costs for technical production reasons. Yugoslavia, Brazil, Mexico and India have a reasonable-sized vehicle market, but for the average developing country low population and low GNP per capita produce tiny markets. In such circumstances, once one goes much beyond basic assembly the technical diseconomies of further import substitution become very substantial. The new practice is to continue imports, but to export certain parts for the entire world market of a particular model: Yugoslavia and Spain make certain parts for the entire Fiat world market; Mexico and Iran will be doing the same for an American firm. These examples exist; but it is not easy to find suitable parts. The best possibilities for international sub-contracting in the vehicle industry are probably spare parts for obsolete models (which Brazil has exported to the United States for some years), and tiny minor fixtures - typically presswork - which the vehicle companies have always bought in anyway.

International sub-contracting by vehicle firms is certainly becoming more common. Berliet, Citroën, and even General Motors have recently sent buyer teams around to potential sub-contractors

in Morocco, partly in response to local pressure. Pressing the multinational vehicle firms for international sub-contracting business may be a good enough strategy, but can be taken too far: at the extreme, a multinational corporation may be prepared to buy any part, at any price, and will simply weight the cost of the Completely Knocked Down vehicle packs it sells to make up for any loss. The developing country is then in a barter situation (i. e., selling parts and buying CKD vehicles in an exchange with the same firm) as with bilateral account trading.

Competition between developing countries for sub-contracting work. With the multinational corporations able to shop around throughout the developing world, one danger which has provoked quite some discussion is that developing countries will compete with each other for international sub-contracting work to such an extent that even the winners in this competition obtain little net benefit. There is probably some justification for this view. Already there is a tendency among developing countries to compete over the length and scope of tax holidays. There is also a trend to provide "ready-made" industrial estates, and often subsidized credit. These estates are probably rather effective as means of attracting international sub-contracting work. The returns to the economy may justify the provision of a certain amount of infrastructure, both items such as power and telephone lines and also perhaps technical training facilities. Subsidized credit and tax holidays are more difficult to defend; it is rather paradoxical for capital-scarce countries to be providing cheap capital to large corporations based in capital-rich countries. More and more developing countries are also instituting export subsidies, or are contemplating doing so; bonus exchange rates are virtually equivalent. Export subsidies can no doubt have an effect in attracting international sub-contracting work, but do involve a variety of dangers; at the extreme, a country can find itself exporting at a foreign exchange loss. Just as overprotection of import substitution is possible (and frequently practiced), so also is overprotection of exporting possible. Korea, with its rapid export growth on the basis of concessional credit, may be getting into this type of difficulty.

In order to maximize its economic gains from industrialization, the strategy of a developing country interested in attracting sub-contracting work should be very different from that which many aspirants are following at present. First of all, the country should consider whether its labor costs and location make it a feasible candidate: many countries would probably find it most difficult to attract international sub-contracting whatever policies they pursued. If international sub-contracting does appear to be a real possibility, the country should avoid overvaluation of its currency, or a legal minimum wage greatly in excess of the scarcity value of labor, and should cultivate a reputation for "stability." Above all, it should

remove bureaucratic obstacles to importation, exportation, and setting up a factory. Cutting red tape may be much cheaper, and much more effective, than grandiose concessions available after two years' negotiation. Once disincentives have been eliminated, the country can examine how far it is necessary or desirable to offer positive incentives. It should then choose the most cost-effective package, and the one that creates the least economic distortions; this is unlikely for example to include long tax holidays or extensive subsidized credit.

The reliability of sub-contracting demand. One of the most frequently mentioned fears about demand for international sub-contracting is that it will suddenly evaporate, causing distress and economic dislocation in the developing country. If a sudden excess of demand in, say, Europe, has come up against limited capacity, then sub-contracting demand may suddenly become large in Portugal or Morocco, but subsequently disappear as new capacity is installed nearer to the center of consumption. On the other hand, if there are more fundamental economic reasons for the sub-contracting demand - for example labor-intensity of the production process - then it is much less likely that demand for sub-contracting will appear and then later vanish. On the whole, it is all too likely that wage differentials, at least in absolute terms, will tend to increase between the developed and developing countries, so that the economic forces behind the move to international sub-contracting will become stronger. As against this, unions in developed countries may sometimes be successful in ensuring that, in a recession, the workers sacrificed are those in the developing country. However, General Instrument Corporation now has 12,000 workers in Taiwan, more than in all its American operations combined: they presumably would be unlikely to sacrifice their Taiwan operation for one in the United States. As time goes by more and more firms will come to have a substantial stake in sub-contracting production in developing countries, and accordingly one would expect them to be increasingly reluctant to jeopardize it.

In theory, it is true, sub-contracting demand could move on from one developing country to others with still lower wages. Over, say, twenty years, this may well actually occur, as wage rates rise: the original sub-contracting country will grade up in its international comparative advantage, as Hong Kong has done, producing and exporting increasingly skill-intensive products. This should cause no great difficulties - no worse than the usual structural problems of development. Indeed, a government may be positively anxious to speed the transition to higher-skill work: Singapore no longer encourages firms to set up plants for low-skill sub-contracting. Sudden disappearance of sub-contracting demand as it shifts to another country is not on the whole very likely, because of the forces

of inertia and the tangible and intangible investments involved. This is clearly so if a firm has a sub-contracting subsidiary - if it has made the necessary arrangements with the authorities, found land, built a factory. It is probably also substantially true where there is no visible investment but when a sub-contractor has been found, quality control and delivery problems have been solved, and a logistical network established. An industry may be 'foot-loose' or 'run-away' as between the U.S. and a developing country, with a possible ratio in comparative wages of up to 20:1, but not as between two developing countries when the possible wage differential is much smaller and the importance of the wage bill in total costs is much reduced.

A more serious danger to the stability of international sub-contracting demand may be technical progress. For example, the weaving of electronic memories may disappear as ferrites are replaced by integrated circuits; and card-punching may disappear as data is fed directly into computers. A generalized answer to the effects of technical progress is impossible; it would vary from product to product. Garment-making seems particularly safe from this point of view. Also, one should almost certainly not regard technical progress as an independent factor: for example, if international sub-contracting permits some type of labor-intensive assembly work to be done cheaply, there will be rather little incentive to devise automatic machinery for that process. Furthermore, if an international electronics firm has found a successful sub-contracting partner or established its own overseas subsidiary, it is unlikely to close down sub-contracting operations because of technical change in one process or product. Instead it will try to switch workers from, say, electronic memories to the assembly of other items - say micro-wave radio equipment, special assembly control panels, or non-standard switchboards.

Effects on general economic development. It would be a mistake to concentrate only on the possible dangers of international sub-contracting, and ignore its most obvious potential benefits. International sub-contracting is a direct source of foreign exchange. It also provides industrial employment at low capital cost per worker, and - unless the government is overgenerous in its concessions to the multinationals - most of the capital required comes from abroad, and would not otherwise be available. Lack of jobs is likely to be the largest single source of social and political disruption in the developing world in the next two or three decades.

It must be admitted that international sub-contracting may heighten the problems of regional imbalance in development. Sub-contracting will tend to concentrate in existing major industrial centers (e.g. Casablanca in Morocco), or possibly in a special Free Trade Zone. But the creation of a Free Trade Zone in a backward region of the country, with the aim of achieving regional balance, may simply fail

to attract clients - unless at the same time extremely good shipping and communications facilities are provided. Especially if wages are fixed at a high level for political reasons, international sub-contracting operations could be a honeypot to attract labor off the land, and in this way create more unemployment than they eliminate. There is some danger that the Mexican border strip will have this effect. If, as is now proposed, manufacture in bond is extended to the rest of Mexico, that could greatly assist in avoiding this danger.

Perhaps the most interesting and difficult question of all is how important are the "spread" effects of international sub-contracting. Here the effects are likely to vary according to the technical type of sub-contracting involved. On the whole, sub-contracting of single processes is likely to have the least spread effects, and certain operations of this type seem naturally to be of an enclave nature. For example, the assembly of semi-conductors in a developing country is rather unlikely to lead on to fabrication of the wafers, by direct backward linkage. However, Taiwan started off with semi-conductor assembly, and will soon be manufacturing television sets for the world market (not just assembly). Also, there have in fact been several cases of backward linkage in Taiwan: production of rayon and polyester for textiles, plastic film for electronics. Whether or not international sub-contracting leads to generalized development depends not only on the type of product but also on the institutional structure of the country concerned, and the inherent skills of the population. Once a multinational corporation has begun to sub-contract certain operations in a particular developing country, it is more likely to sub-contract other ones, as the perceived risk diminishes. A country can slowly raise the skill level of the labor-intensive operations which it performs, from sewing garments to the production of scientific instruments or photographic equipment - making lenses is particularly labor-intensive. Sub-contracting in a developing country may also offer the quality control advantage that 100 percent inspection and testing become economically feasible. Even with the most 'enclave' type of sub-contracting, there are some benefits from the training of an industrial labor force. There is some limited evidence that local value-added tends to rise in relation to gross value: as Table 1 shows, for the developing countries as a whole, the ratio of dutiable value to gross value for U. S. Item 806.30 and 807.00 imports has risen in every year since 1967. Of the five major sub-contracting countries, it has risen every year since 1966 in Taiwan, and in all five countries it has risen since 1970.

Nevertheless, except conceivably for a few small countries heavily dependent on foreign trade, international sub-contracting is unlikely to prove the new panacea for economic development. In Mexico, Taiwan, and Korea, where international sub-contracting has the greatest importance, the gross value of international sub-contracting

exports has only reached 5-15 percent of the total value of exports. Of course, international sub-contracting on a large scale only dates from about 1965, and is growing fast, so that it is quite possible that in some countries in the future international sub-contracting will exceed its present importance relative to the total economy in Mexico, Taiwan, and Korea.

Economic and Political Effects Within Developed Countries

There have been lurid accounts in the American union press of the enormous profits made by companies which have started up off-shore operations; and no doubt some of the first companies to adopt this particular production innovation did do extremely well. But unless a particular market is very tightly cartelized, this must be a temporary situation. As the use of off-shore facilities becomes generalized, prices either come down, or fail to go up with inflation: this has clearly happened in the case of integrated electronic circuits (where the price for one common type of circuit fell from U. S. \$0.70 to \$0.14 in a year). Thus on the whole the consumers in the developed countries do stand to benefit from international sub-contracting. However, consumers do not usually constitute a powerful political lobby in most developed countries: they are typically much weaker politically, much less well informed, and much less organized than the producers, be they employers or employed.

It is here that one finds one of the most important political differences between international sub-contracting by producer firms and direct exportation of manufactures by developing countries. With direct exporting, both firms and unions in the developed country will lobby against the imports. However, with international sub-contracting by producer firms, only the unions will lobby seriously against imports, for the obvious reason that the firms will be benefiting from the trade themselves. This no doubt helps to explain why, despite political resistance, it has been possible for imports to take over nearly all the United States market for many consumer electronic products, whereas much more limited penetration of the United States textiles market (less than 15 percent of consumption of cotton textiles) led to official 'voluntary' quotas on cotton textiles.

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